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HF ANTENNA GAIN PATTERN MEASUREMENTS: EXPANDED LITTLE IDA PROGRAM

Joseph J. Simons
Frederick C. Wilson
Richard A. Schneible

TECHNICAL REPORT NO. RADC-TR-68-248
September 1968

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Rome Air Development Center
Air Force Systems Command
Griffiss Air Force Base, New York

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AFLC, GAFB, N.Y., 9 Oct 68-72

FOREWORD

This report was prepared under Project 5582, Task 558202, by personnel of Rome Air Development Center, Environmental Studies Section, EMASA. The RADC Flight Test Division (EMF), the Measurement Section and Test Operations Unit (EMCVM) of the RADC Communications Division, and the Heavy Military Electronics Division of General Electric Company, Syracuse, N. Y., assisted in obtaining the data discussed herein. Special acknowledgment is given to Donald McCoy and Robert Wengenroth of General Electric; and to Donald Long, Charles Lupica, Capt. Robert Welch, Capt. William Freeman, and Capt. James Hayes of RADC, EMCVM.

Distribution of this report is restricted under the U.S. Mutual Security Acts of 1949 to protect techniques revealed herein.

This Technical Report has been reviewed and is approved.

Approved: Earle H. Filer
EARLE H. FILER
Acting Chief, Space Surveillance
and Instrumentation Branch
Surveillance & Control Division

Approved: Joseph Falk
WILLIAM T. POPE
Acting Chief
Surveillance and
Control Division

FOR THE COMMANDER: Irving J. Gabelman
IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

This report describes the data collection, reduction, and processing techniques employed in an antenna gain measurements program. This gain measurements program is an integral part of the overall Expanded Little IDA effort.

The gain patterns of transmitting antennas located at Thule, Greenland; Keflavik, Iceland; and Coco Solo, Panama Canal Zone were determined and the results reported.

Site and aircraft instrumentation used to obtain the data and manual and computer processing methods used to reduce the data are discussed.

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I. INTRODUCTION

This report describes the measurement and data processing techniques used in determining the gain patterns of full-scale high frequency (HF) antennas located at four sites utilized in the RADC Expanded Little IDA Program (ELIDA). Transmitting sites are located at Pingorssuit "P" Mountain, Thule AFB, Greenland; Site Dye 5, Keflavik NAS, Iceland; and Coco Solo Test Annex, Panama Canal Zone. The transmit sites beam their signals to a central receiving site located at the Starr Hill Test Annex, Remsen, N.Y., situated 19 miles north of Griffiss Air Force Base.

The measurement technique involved the utilization of an Air Force NKC-135 refueling tanker instrumented with several HF receiving chains. The data processing and reduction procedures involved both manual and computer techniques.

The antenna measurements were performed in support of contract AF30(602)-3946, Expanded Little IDA, with the General Electric Company, Heany Military Electronics Division, Syracuse, New York. GE operated and maintained these sites under this effort. Both RADC and GE personnel participated in the measurement program. Data reduction was primarily performed by the Environmental Studies Section of RADC, with the consultant services of GE engineers.

This report discusses the techniques employed and results obtained for the antenna gain/flight tests measurements of the antennas located at the Thule, Iceland, and Panama transmitting sites. The Panama and Thule tests were conducted during August and October 1966, while the Iceland measurements were conducted during October 1967. Some preliminary measurements have been made at the Starr Hill receiving site, but additional tests are required. Results of Starr Hill measurements will be reported on at a later date.

A discussion of the Expanded Little IDA Program, which generated the requirement for antenna gain patterns, is presented in Appendix A. One investigation involves the measurement of high frequency signal losses associated with the individual modes that propagate over each path. The analysis of propagation loss requires (a) a determination of the total loss between transmitter and receiver, and (b) the separation of known losses and gains.

The transmitting and receiving antenna gains must be removed from the loss measurements so that the data will be independent of the antenna used. This experiment is being performed over paths that have a 2000 nm. range, which is the limiting distance for propagation via the one-hop F (1F2) mode. When propagating over these ranges the 1F2 mode is received at elevation angles between

-1° to 4°, while the two-hop F mode is received at elevation angles between 12° and 20°. Therefore, to perform a loss measurement on the individual modes of propagation, the antenna gain patterns must be measured as a function of elevation angles in the range from -1° to $+20^{\circ}$.

II. SITE INSTRUMENTATION

A. EQUIPMENT

The measurement technique employed in the tests of the Thule, Iceland, and Panama transmitting antennas was identical. Signals were transmitted from the ground and received in the NKC-135 aircraft. A block diagram of the instrumentation used at the transmitting sites for the tests is shown in Figure 1.

Four transmitting systems, each tuned to a different frequency, were time multiplexed to the antenna under test. Each transmitting system consisted of (1) a frequency synthesizer, (2) an RF exciter, and (3) a 1 kw to 3 kw amplifier. These systems were sequentially connected in turn to the antenna under test by a sequence keyer. Each transmitter was keyed on for one second and off for three seconds. Therefore, four frequencies were transmitted in four seconds. Power monitoring was accomplished by connecting an oscilloscope to a directional coupler so as to maintain a constant power level for all transmitters during each of the tests.

The pulsing rate of one second on, three seconds off, provided adequate sampling of the antenna pattern, permitted four-frequency operation without complex multicoupler techniques, and allowed the noise and interference levels to be checked between pattern samples. Thus, in effect, four gain patterns were measured in one radial aircraft flight pattern, reducing flying time by 75 percent. The data rate using this pulsing technique was adequate for measuring patterns below about 25^{o} elevation angle. Above 25^{o} the data rate is too slow to represent the fast-changing pattern. The ability to measure the noise and interference level permitted the analysis of some data which would otherwise have been unusable because it indicated when noise levels were high and also aided in selecting frequencies that correspond to low noise levels. Also, when signal levels are close to the noise level, a separate measurement makes it possible to correct for its influence on the signal.

B. ANTENNAS

1. Thule

A Granger Associates, Model 726-5, antenna was installed at the "P" Mountain Site. This antenna is located on a rocky point between two troposcatter antenna installations. From this site there is an unobstructed path south, with the horizon being Baffin Bay 2600 feet below. The dip angle to the horizon is about 1^{o} from the

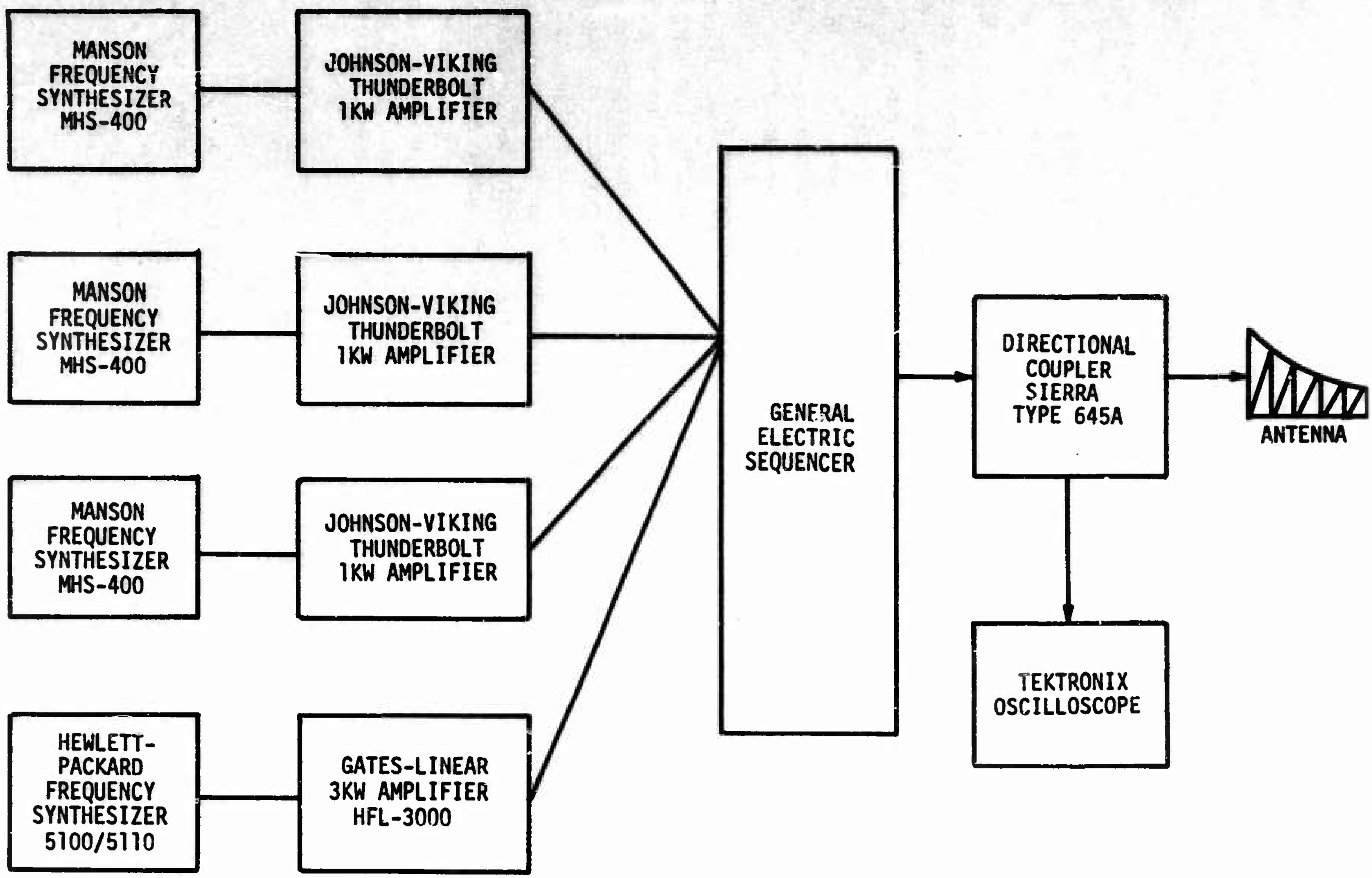


Figure 1. Transmitting Equipment

2600 ft. elevation of the site. Figures 2 and 3 are photos of the Thule antenna. The specifications of the Granger 726-5 are:

Frequency Range - 4-64 MHz

Type - Log-Periodic Monopole

Application - Receive and Transmit

Power Capacity - 1 KW average, 30 KW PEP

Input Impedance - 50 ohms

Polarization - Vertical

2. Keflavik (Dye 5), Iceland

A Granger 726-5 LPV (identical to that at "P" Mt.) was also installed at Site Dye 5, Iceland. The Iceland antenna is located at a seaside site, very close to the ocean. The patterns of this antenna were subject to tidal effects.

3. Coco Solo, Panama Canal Zone

The measurement antenna at Coco Solo is a log-periodic, vertically polarized dipole, ALL-Products Co. Model LPV 12-A. This antenna also has a frequency range of 4 to 64 MHz and its specifications are similar to the Thule antenna. The Coco Solo site, located on the Atlantic side of the Canal, is situated in a swampy area about one foot above sea level. The ocean tides have a range of only about nine inches. The data have shown that this small tide has no measurable influence on the antenna pattern.

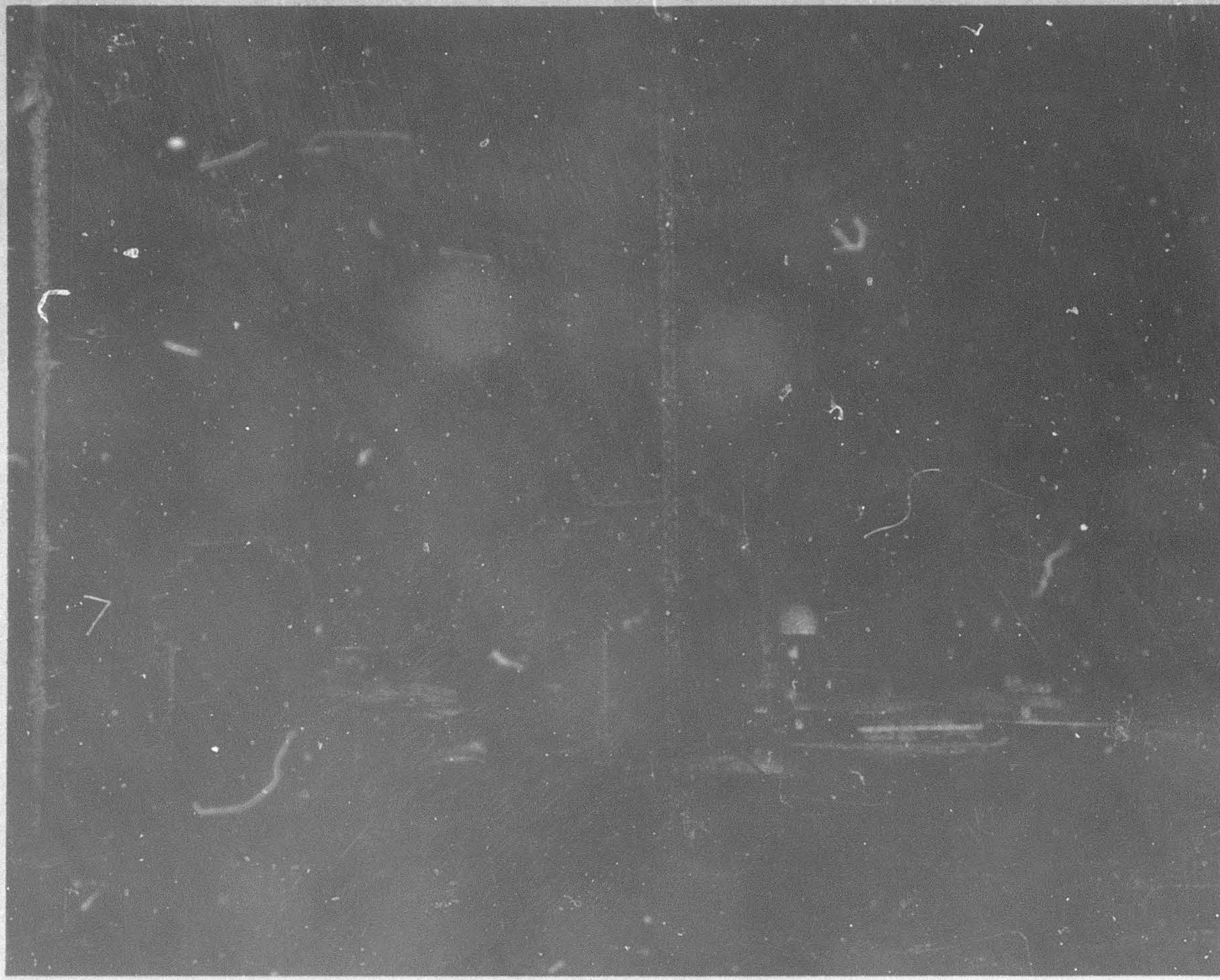


Figure 2. Thule Antenna

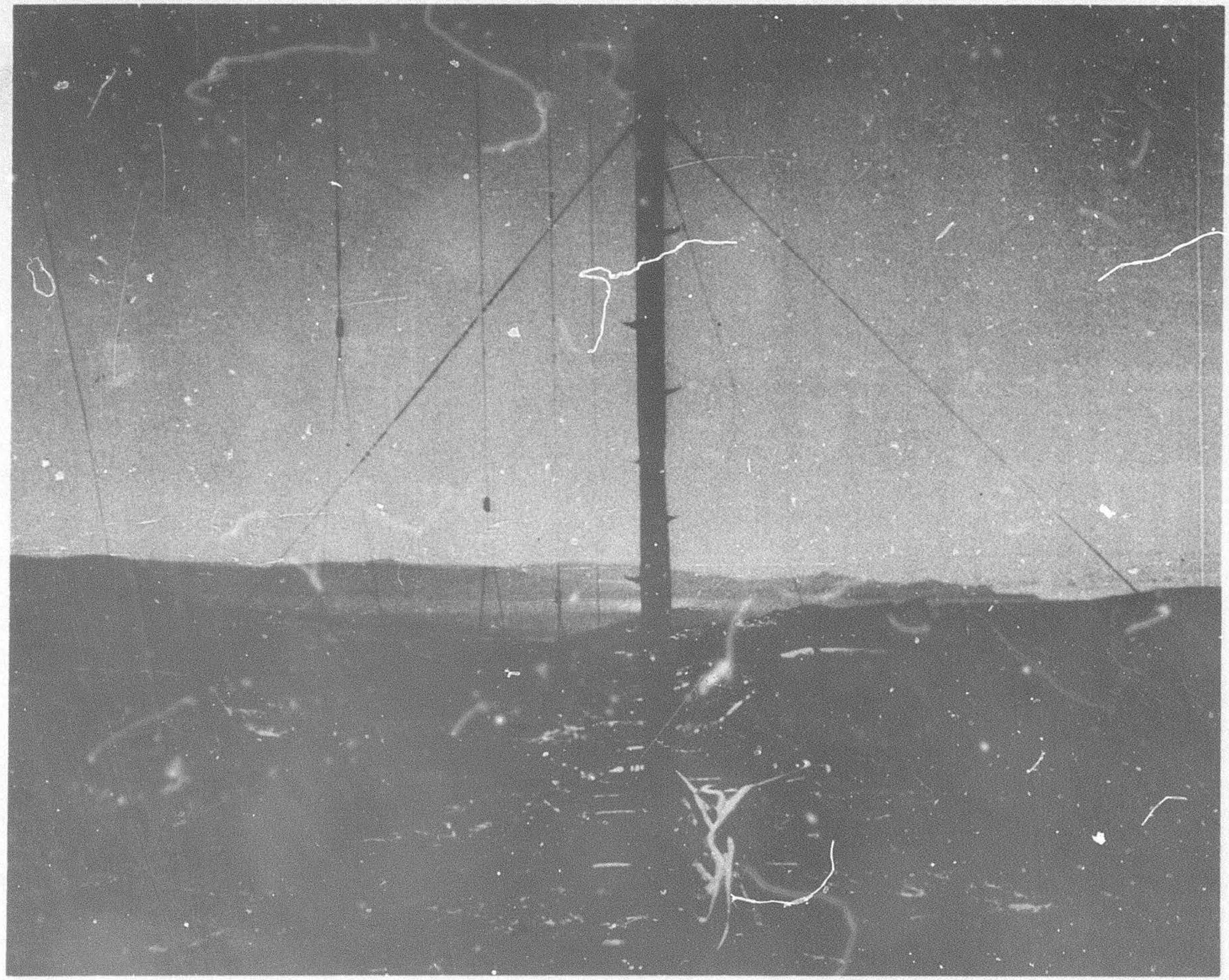


Figure 3. Thule Site - Looking Along Boresight

III. AIRCRAFT INSTRUMENTATION

An NKC-135 RADC aircraft was instrumented with (1) a four-channel receiving and recording system which is compatible with the high frequency transmitting system and (2) a receiving loop antenna which could be oriented to receive either vertically polarized or horizontally polarized radiation. A block diagram of the aircraft instrumentation is shown in Figure 4. Photos of the aircraft and receiving loop are shown in Figures 5 and 6.

Once each signal has been received by the two-turn loop and balun, it is amplified and passed through a switching attenuator/directional coupler network. As illustrated on the diagram, the signal is then coupled to one of four receiving and recording chains. Each chain is composed of a step attenuator, and an R-390 HF receiver. The AGC voltage level from each receiver, which is nearly logarithmic with signal level, is recorded on a four channel Brush/Mark-200 analog recorder. As shown in Figure 4, a Hewlett-Packard Frequency Synthesizer, Model No. 5100/5110, and an attenuator are used in calibrating each receiver channel.

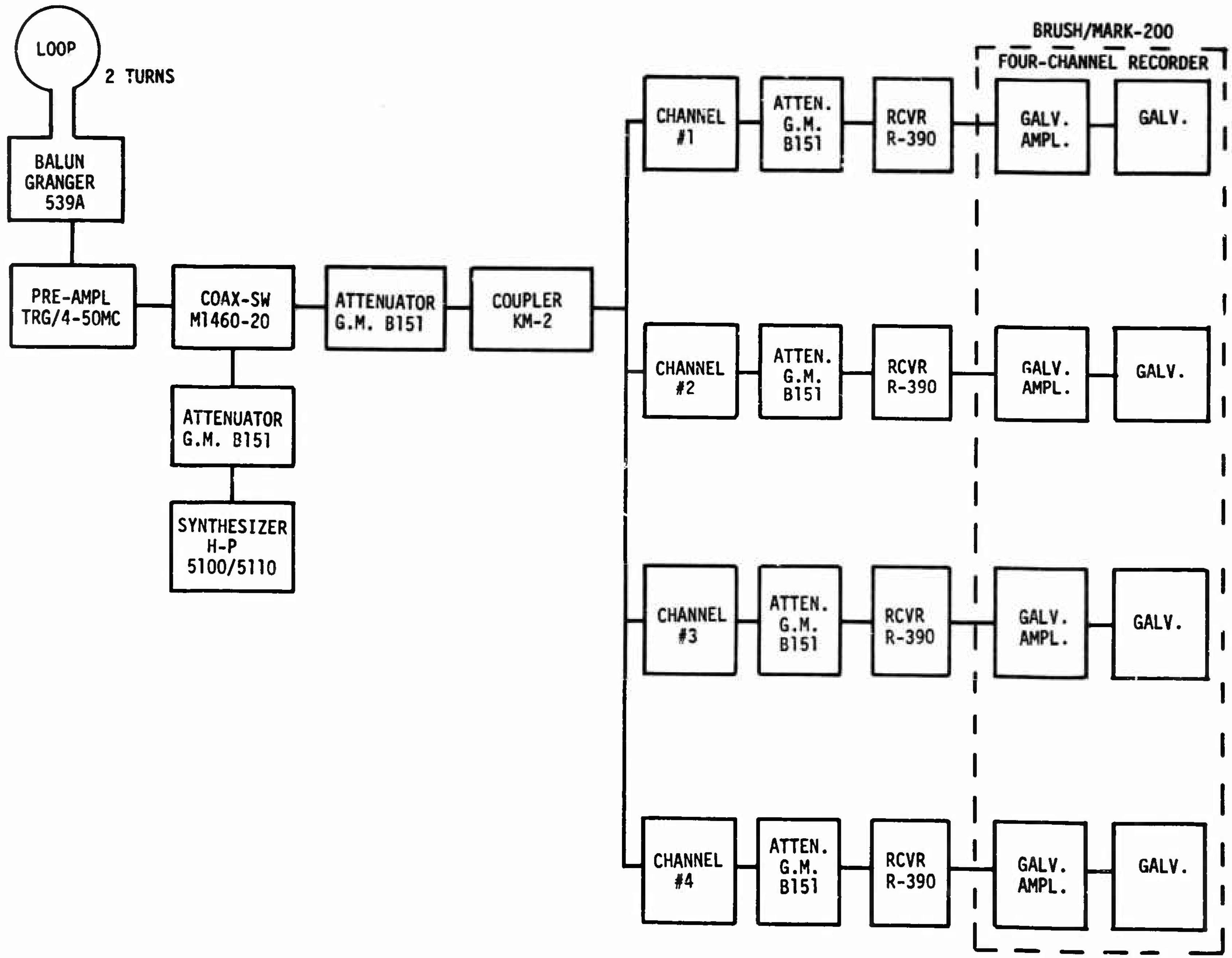


Figure 4. Aircraft Receiving Instrumentation

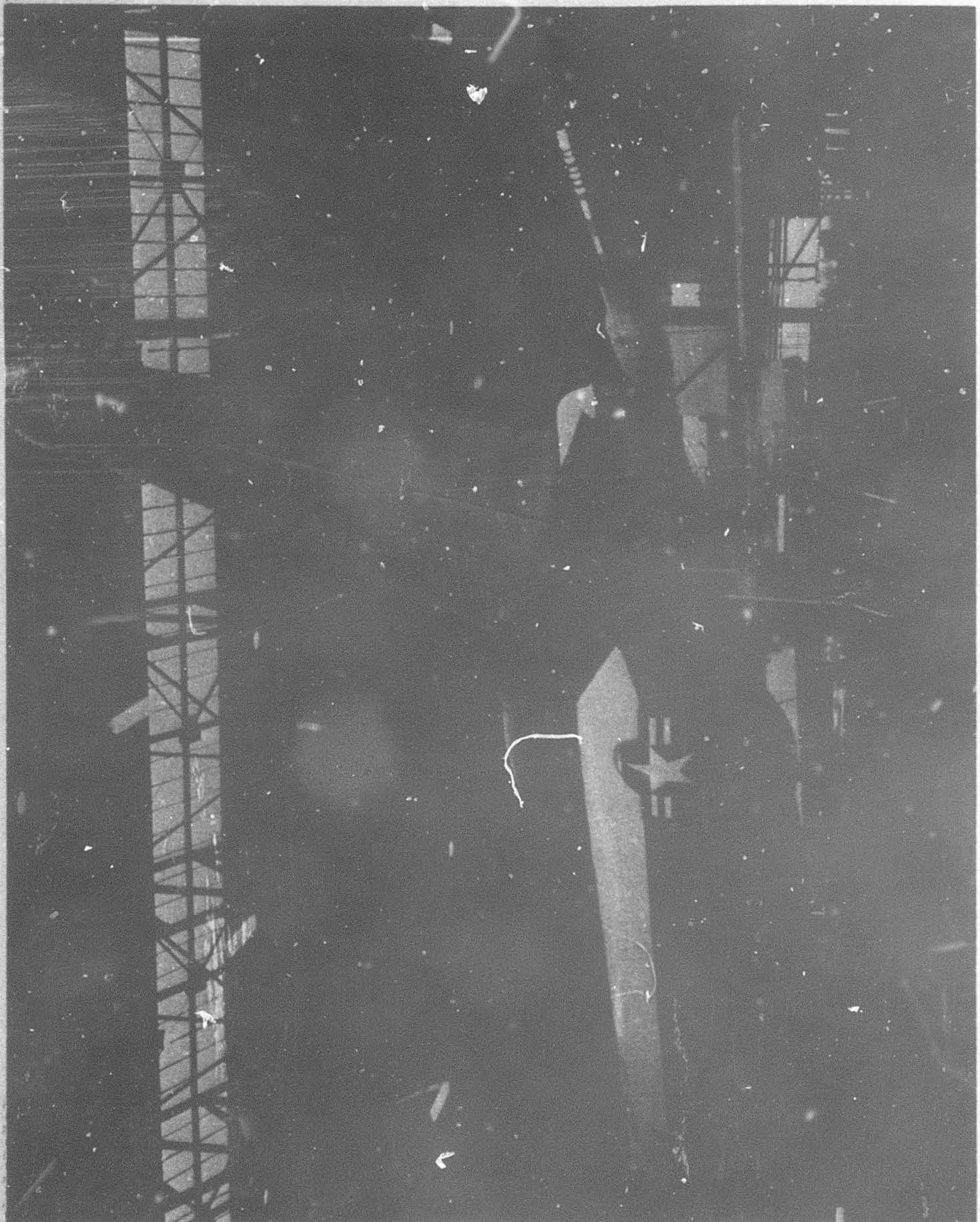


Figure 5. NKC-135 Flight Test Aircraft

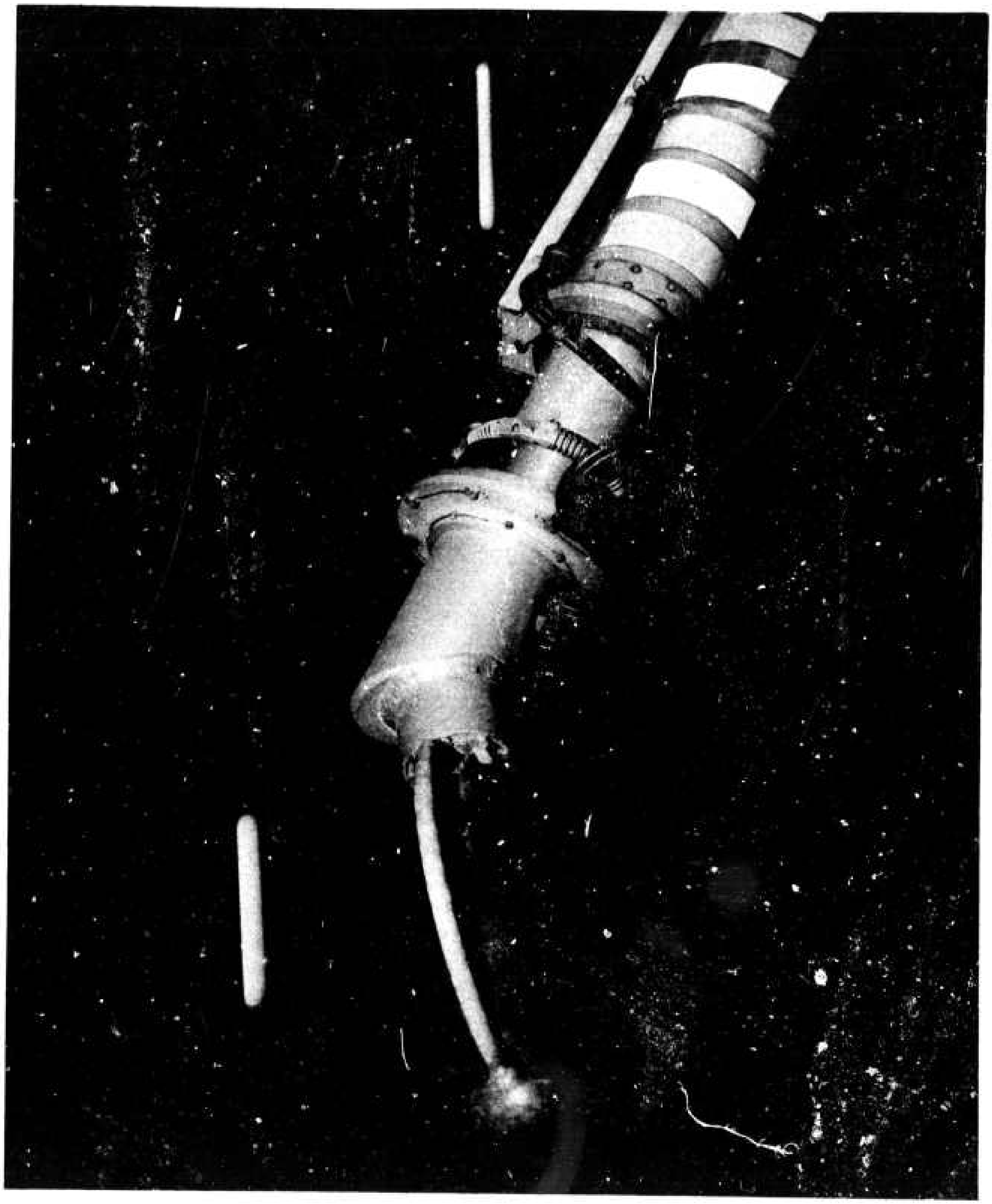


Figure 6. Receiving Loop

IV. DATA COLLECTION PROCEDURE

The same technique was used at all locations for the collection of antenna pattern data. At each site and for each antenna gain measurement, the aircraft flew a radial flight plan out along the boresight of the antenna and also at plus and minus 5^{o} and 10^{o} off-boresight. Data taking commenced when the aircraft was directly over the site (at the zenith of the antenna). The radial patterns were flown to ranges of 300 nautical miles from the site, and at altitudes between 27,000 and 31,000 feet. However, altitude was kept constant through each individual run. With respect to antenna elevation angles, these radial flights correspond to elevation angles of 90^{o} to -1^{o}. As previously mentioned, primary interest was centered on data taken between elevation angles of -1^{o} and 20^{o}, which covers the range over which the lower order dominant modes (1F, 2E, 2F, etc.) are launched.

The gain pattern of each antenna was measured as a function of eight frequencies in the 9 to 30 MHz region. Therefore, a total of forty (8 frequencies, 5 radials per frequency) successful data-taking radials were required. To check the validity of the data, the boresight radials were repeated. In addition, radial missions were scheduled to check the cross-polarized response of the antenna under test. This was accomplished by changing the polarization of the aircraft loop antenna (i.e., from vertical to horizontal polarization).

Range information (that is, knowing the location of the aircraft at any given time) is one source of error in gain measurements. Navigation procedures were set up so that the range of the aircraft from the transmitting antenna could be determined continuously as the aircraft flew along a specific heading. For an aircraft flying at a constant altitude, the location or specific range of the aircraft from the antenna under test corresponds to a specific antenna elevation angle.

In the case of the Panama and Iceland measurements, a doppler-radial navigation radar, APN-81, located on the aircraft was used in determining range. Range marks, in five and ten nautical mile increments, were recorded on the same recorders used for the signal test data. This navigational system is specified as having a range accuracy of plus or minus one nautical mile. For the Thule measurements, this system was supplemented by use of the approach radar, FPS-47, located at the main base at Thule. This radar was used to position the aircraft directly over the site on each radial run. In the Panama and Iceland tests, visual techniques were employed in positioning the aircraft so as to establish the site as zero reference for each radial.

V. DATA REDUCTION

A. THE LOSS EQUATION

The signal power, p_r, present at the receive antenna terminals of the flight test aircraft is given by the familiar equation:

$$P_r = \frac{p_t g_t g_r}{1_{bf}} \qquad (1)$$

where:

p_t = power output at the terminals of the transmitter

g_t = gain of the transmitting antenna

g_r = gain of the receiving antenna

1_{bf} = free space loss

equation (1) can be expressed in decibels as

$$P_r = p_t + g_t + g_r - 1_{bf} \qquad (2)$$

By rearranging terms, the gain of the transmitting antenna can be expressed as:

$$g_t = P_r - p_t - g_r + 1_{bf} \qquad (3)$$

Thus the gain of the transmitting antenna can be calculated provided the transmitted power, received power, receiving antenna gain, and free space loss are known.

1. Transmitted Power

Power levels were determined at the transmitter site by using a Tektronix oscilloscope to measure the voltage across a 50-ohm load in the arm of a Sierra directional coupler connected between the transmitter and the antenna. At the end of the program, the oscilloscope was checked by inserting a 20 dbm signal from an HP 606A signal generator. Power was monitored throughout each data run so that any level changes could be noted.

2. **Received Power**

On the aircraft, received power is recorded directly on chart recorders using calibrated receivers. Calibration runs are made for each radial to check drift. Attenuators are inserted in the receiver chain so that the recorders are kept within their linear range throughout the data period. The value of the attenuators in the circuit along with range marks from the navigator are entered on the chart records by the operator.

3. **Loop Gain - G_r**

The calculation of the loop gain is one of the most difficult parts of this experiment. In order to calculate this correctly it is necessary to fly the aircraft against an antenna whose pattern is known. A horizontal dipole, located at RADC's Verona Test Site will be used to calibrate the loop for horizontal polarization. Measurement techniques to determine the gain of the loop for vertical polarization are being investigated. This investigation involves a determination of a standard reference antenna whose pattern is well known. An interim method was devised that involvod the selection of a point on the antenna pattern at an elevation angle that was relatively free of ground effects. The gain at this point was set equal to the theoretical gain of the antenna. Since the relative gains were known, this gave the absolute antenna patterns.

4. **Free Space Loss**

The free space loss incurred by a high frequency wave of wavelength λ transversing a distance R is given by:

$$L_{bf} = \frac{\lambda^2}{4\pi R^2} \tag{4}$$

In our case, R is the slant range from the transmitting site to the airplane and is calculated in the following manner. Referring to Figure 7

$$\theta \text{ (radians)} = \frac{R_g}{a} \tag{5}$$

and by the law of cosines

$$R^2 = a^2 + (a+h)^2 - 2a(a+h) \cos \theta \tag{6}$$

Since λ is known, free space loss can be calculated knowing the height of the airplane and the ground range between the transmitter and airplane.

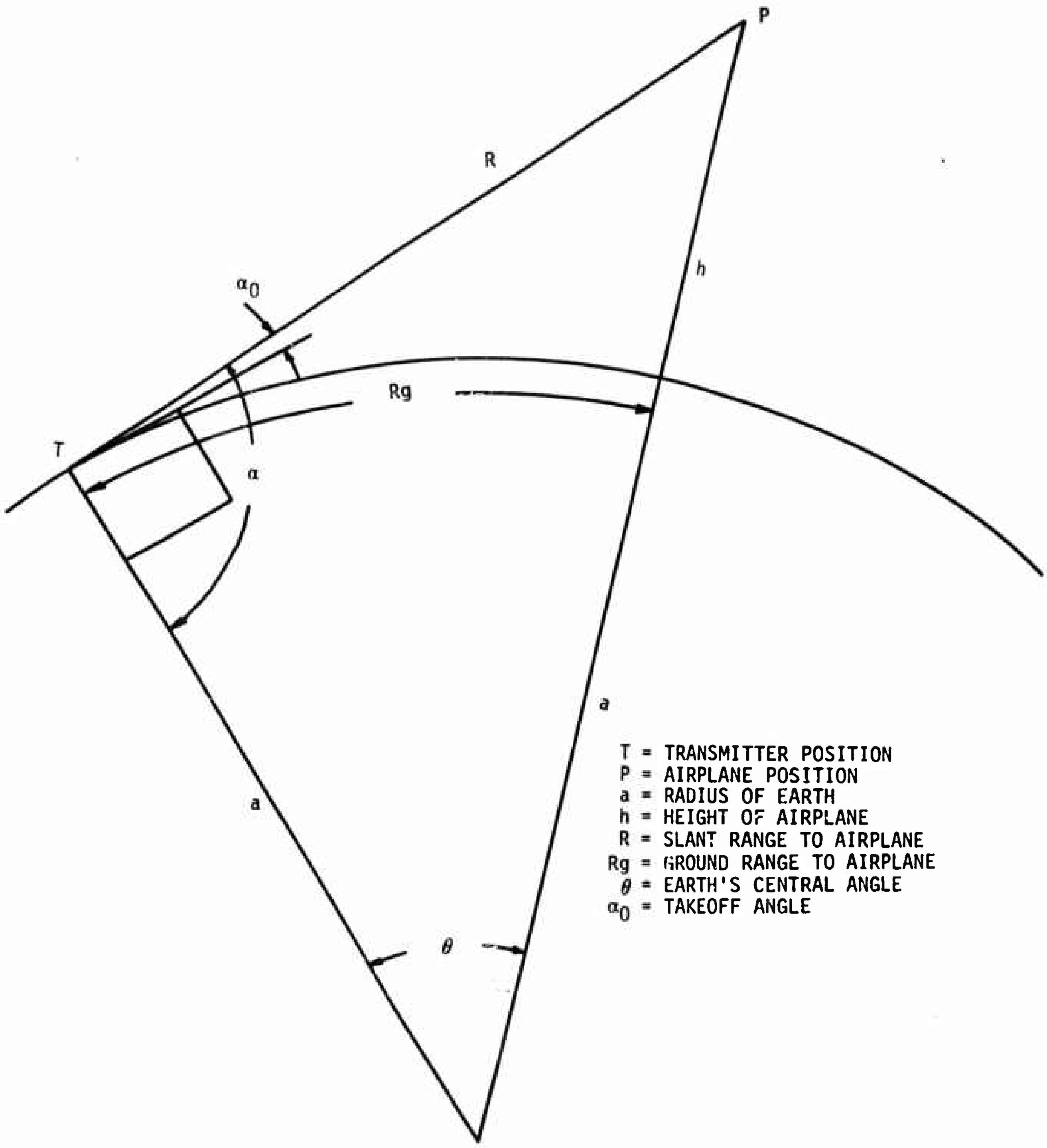


Figure 7. Test Geometry

B. ELEVATION ANGLE

1. Geometrical Angle

Although elevation angle, as such, does not appear in the basic equation for determining gain of the transmitting antenna, it is required for data presentation so that the antenna gain patterns can be made as a function of a common factor. With gains plotted versus elevation angle, direct comparisons of the gain change with frequency, off-boresight angle, etc., can be made. This method of data presentation is advantageous in comparing the patterns of different antennas.

Referring again to Figure 7, the geometrical angle α_0 can be calculated by using the law of cosines:

$$(a+h)^2 = R^2 + a^2 - 2aR\cos\alpha, \tag{7}$$

or

$$\cos\alpha = (R^2 + a^2 - (a+h)^2)/\ , \tag{8}$$

and since $\alpha = 90 + \alpha_0$ (9)

$$\cos(90 + \alpha_0) = R^2 + a^2 - (a+h)^2/2aR, \tag{10}$$

and

$$-\sin\alpha_0 = (R^2 + a^2 - (a^2 + 2ah + h^2))/2aR, \tag{11}$$

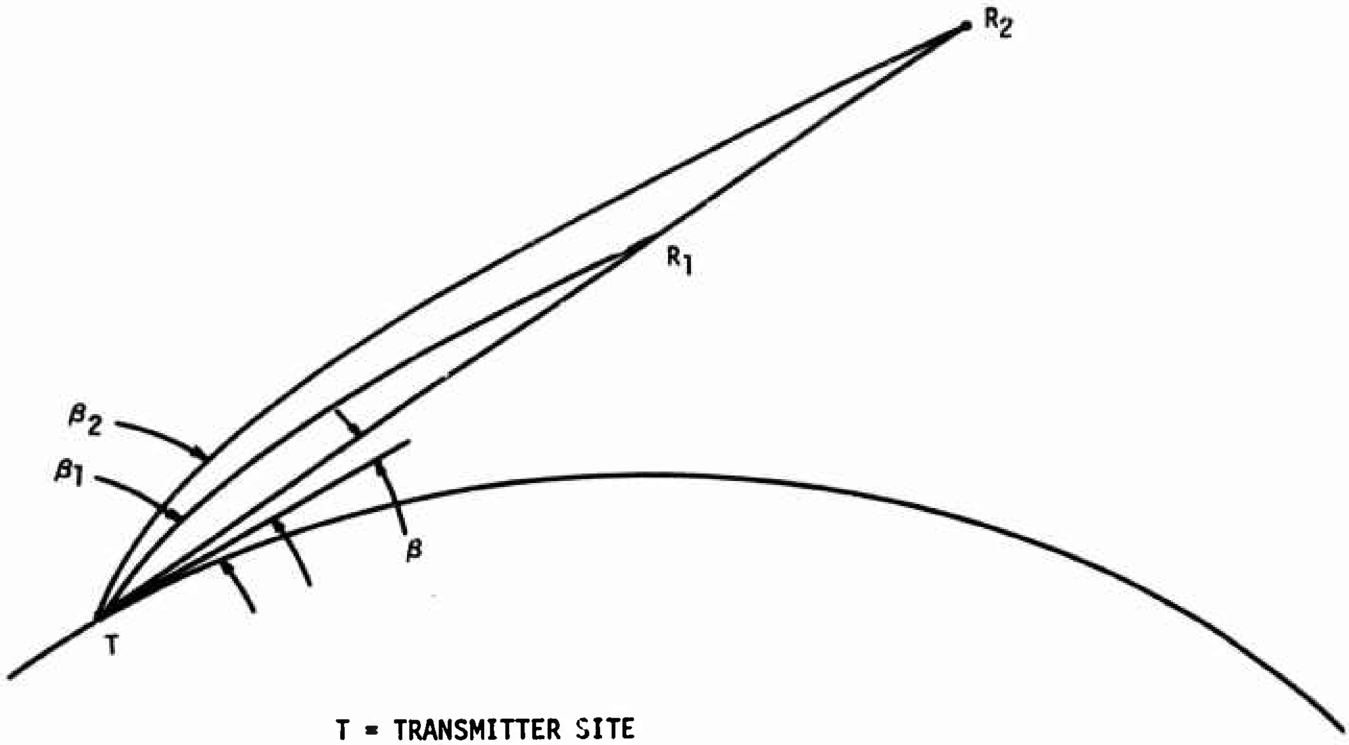
or

$$\sin\alpha_0 = (2ah + h^2 - R^2)/2aR \tag{12}$$

All the quantities in the above equation are known and thus the calculation of the geometrical elevation angle can be made.

2. Tropospheric Correction

Due to tropospheric refraction, the geometrical angle is not the angle at which the energy is radiated from the antenna. It is necessary to calculate the antenna patterns in terms of this latter angle which we shall call the true angle. This can be seen from Figure 8, which shows how the energy from a transmitter located at T, leaves the antenna at different angles to intercept two receivers, R_1 and R_2, located at the same geometrical angle. Thus antenna patterns flown at different heights would give different results unless these refinements were made. These corrections in elevation angle must be made before the data is presented, and have been made part of the computer program, ANTPAT, which is discussed in the next section. The computer employs a table look-up technique using values for the refraction data as published in Reference 7.



T = TRANSMITTER SITE
R_1 = RECEIVER #1
R_2 = RECEIVER #2
β = GEOMETRICAL ANGLE TO R_1 and R_2
β_1 = TRUE ANGLE TO R_1
β_2 = TRUE ANGLE TO R_2

Figure 8. Refraction Effects

VI. COMPUTER PROCESSING

For efficient processing of the antenna pattern data, three basic computer programs were written in Fortran for use with RADC's Control Data 1604 Computer. Programs written were named ANTPAT, TAPPLT, and DATAVE. Listings of these programs can be found in Appendix B. Comment cards have been added to identify the main sections. Sample outputs of each of the programs can be found in Section VII of this report.

A. PROGRAM ANTPAT

Figure 9 is a block diagram of Program ANTPAT. ANTPAT is the basic data reduction program. It uses the antenna pattern data which is punched onto input cards, performs all the necessary calculations, i.e., slant range, free space loss, etc., and provides a tabulation of antenna gain, take-off angle, and other selected variables. It records all information necessary for further processing by the other programs on a magnetic tape.

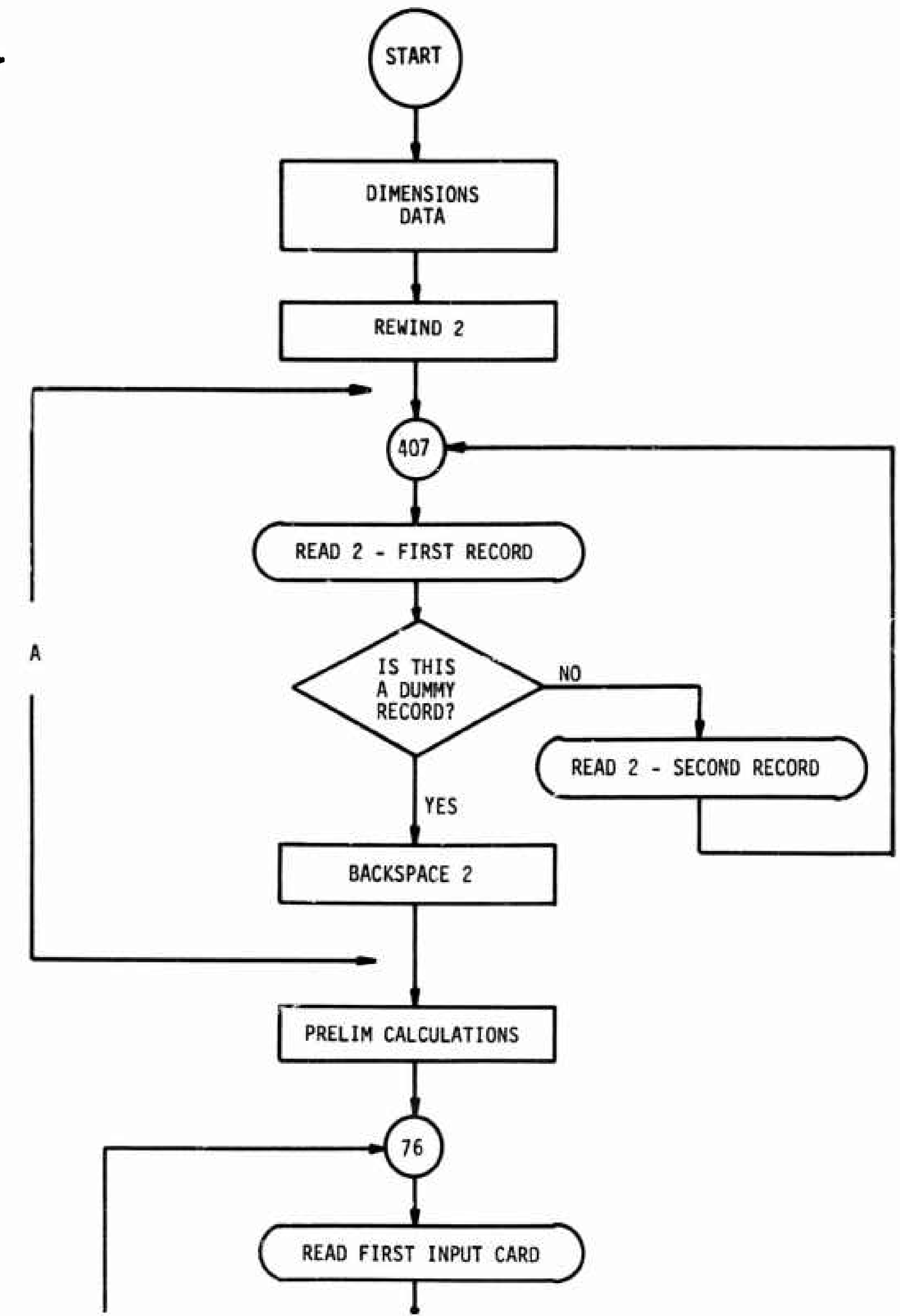
1. Data Requirements

The information necessary for ANTPAT to calculate the gain of the transmitting antenna can be summarized from Section V as follows:

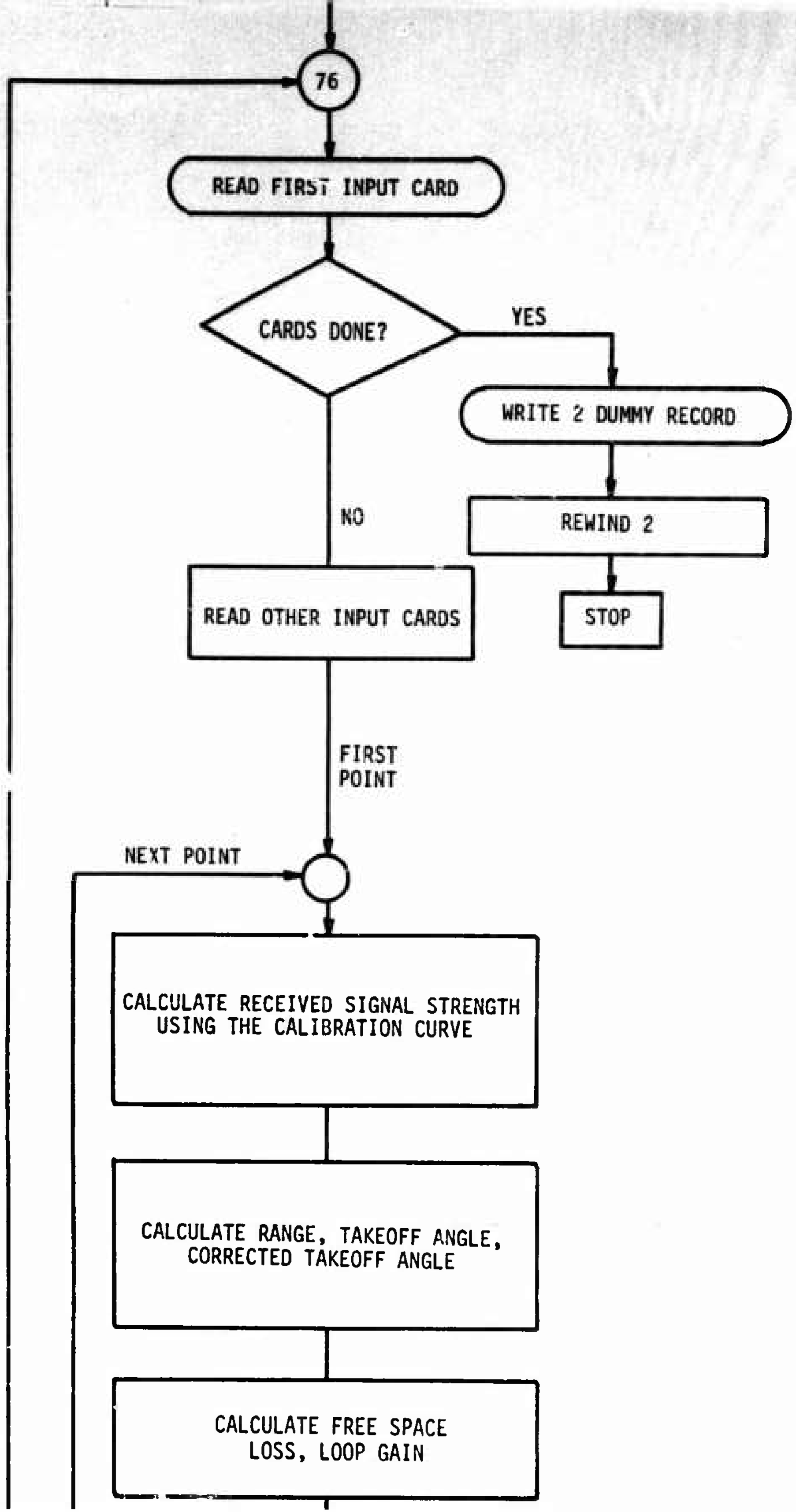
- transmitter power
- received power
- attenuator settings
- receiver calibration data
- frequency of transmission
- height of aircraft
- ground range from transmitter to aircraft
- loop gain
- tropospheric angle corrections

In addition certain information is necessary to identify features of the data run itself:

- site identity and loop polarization
- date of the run


START
DIMENSIONS DATA
REWIND 2
407
READ 2 - FIRST RECORD
IS THIS A DUMMY RECORD?
NO
READ 2 - SECOND RECORD
YES
BACKSPACE 2
A
PRELIM CALCULATIONS
76
READ FIRST INPUT CARD

B.



76
READ FIRST INPUT CARD
CARDS DONE?
YES
WRITE 2 DUMMY RECORD
REWIND 2
STOP
NO
READ OTHER INPUT CARDS
FIRST POINT
NEXT POINT
CALCULATE RECEIVED SIGNAL STRENGTH USING THE CALIBRATION CURVE
CALCULATE RANGE, TAKEOFF ANGLE, CORRECTED TAKEOFF ANGLE
CALCULATE FREE SPACE LOSS, LOOP GAIN

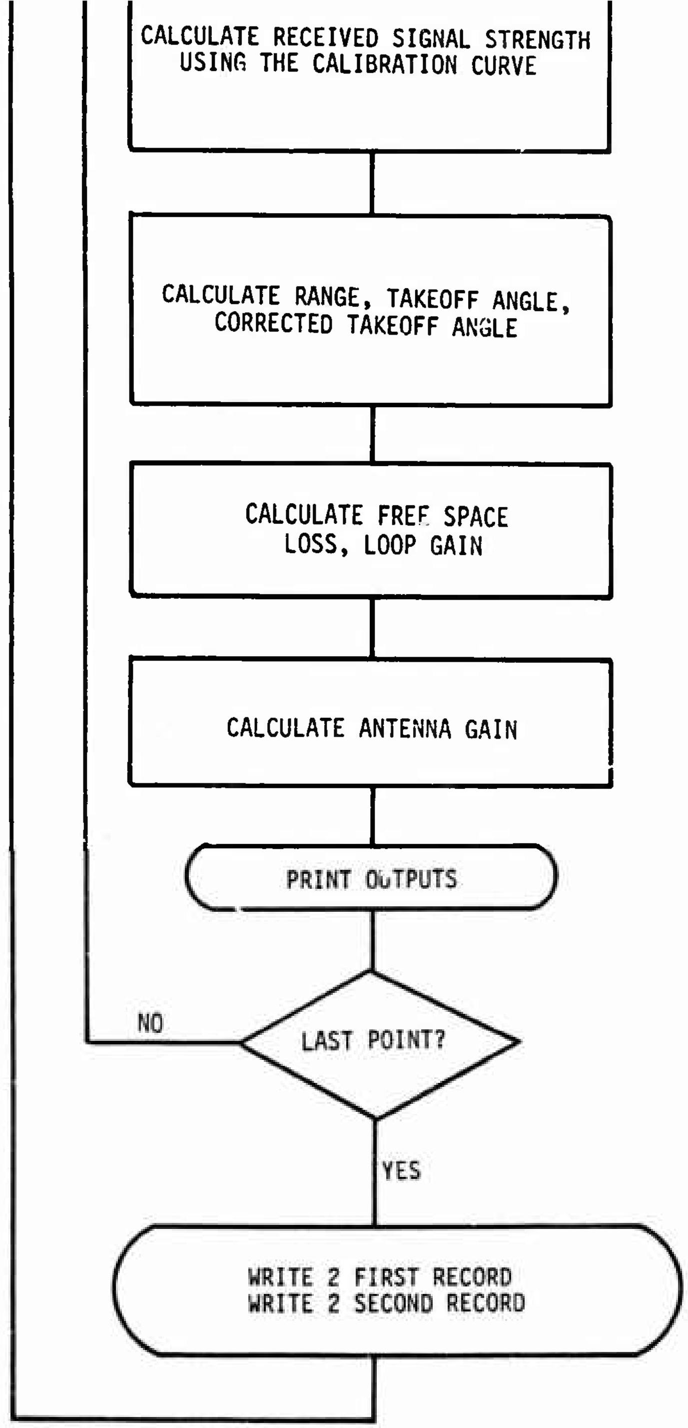


Figure 9. Block Diagram - Program ANTPAT

C

- heading
- run number (the sequential number of the run in the flight test plan)
- time of day (needed to help assess certain geophysical effects, e.g., weather, tides, etc.)
- identifying number of the receiver used for a specific run and frequency

The tropospheric corrections and loop gain calculations were made an integral part of ANTPAT and are not a part of the input data. Transmitter power was measured at the transmit site. Received powers and calibration data were recorded by the receiving system. From a practical point of view, it was found to be a difficult and time-consuming task to convert the data points directly to power received in dB's using the calibration curve. For each run, therefore, the points on the calibration curve and the data points were read with reference to the divisions on the chart paper. The computer calculates the data point locations on the calibration curve and their corresponding received power values.

Readings of the data points were made usually in five nautical mile intervals out to 60 miles and every ten nautical miles thereafter. Any obvious peaks and nulls in the data which do not occur at these specific range intervals were recorded so that their full extent could be assessed.

The site identity and polarization are defined in the computer program by a variable name, NPOL. This variable must be specified by a Fortran statement before each computer run. Consequently every computer run must consist of data from the same site and of the same polarization.

All of the other quantities listed above are either entered as part of the Flight Test log or as notes on the chart recorder paper.

2. Input Data Format

ANTPAT was written as an input program for all the data specified in Section VI. A. 1 above. Data must be supplied to the program in the following order and format.

a. Information header card

Columns	Format	Variable
1-6	I6	date
7-9	I3	heading
10-11	I2	run number

Columns	Format	Variable
12-15	I4	time
16-25	F10.0	altitude (K feet)

b. Data header card

Columns	Format	Variable
1-2	I2	number of data points
3-4	I2	receiver number
5-14	F10.0	frequency (MHz)

c. Power card

Columns	Format	Variable
1-10	F10.0	power in DBM

d. Calibration Data

Columns	Format	Variable
1-4, 5-8, --,69-72	18F4.1	calibration data (DIV)

e. Data Points

Columns	Format	Variable
1-5, 6-11, --,71-75	15F5.2	ground range (NM)
1-5, 6-11, --,71-75	15F5.2	data points (DIV)
1-5, 6-11, --,71-75	15F5.2	attenuations (DB)

3. Calculations and Output Form

After reading the required input data as above, ANTPAT makes all essential calculations as described in Section V. The determination of loop gain is done separately in a subroutine. The other calculations are all straight-forward and will not be elaborated on further. The block diagram (Figure 9) and the listing in Appendix B should enable the reader to follow the program with little difficulty.

The tabular output of ANTPAT (see Section VII for an example) provides a quick look at the data to check for obvious errors before further data processing is carried out. In addition, ANTPAT writes all data necessary for the subsequent programs on a magnetic tape. All data points are included in the tabular output of ANTPAT. Data taken at angles greater than twenty-five degrees are of a secondary interest and are not written on the tape. The first time the program is run, Section A (see Figure 9) is removed. Data are recorded on tape followed by a dummy record. For each additional run, Section A is reinserted. The program adds on to the data tape, erasing the dummy record and moving it to the end. The dummy record serves as a flag for subsequent programs to indicate the end of the data.

B. PROGRAM TAPPLT

Program TAPPLT is the basic data plotting program. It uses the tape written by ANTPAT and performs a search for selected data. It then writes a magnetic tape which is compatible with RADC's EAI 3500 data plotter system. Gain versus elevation angle plots can be obtained off line using this system. Figure 10 is a basic block diagram of TAPPLT.

TAPPLT plots the repeat runs for a given site, frequency, heading, and polarization on the same graph so that the repeatability of the patterns as well as the patterns themselves can be studied. A major part of the program deals with the output of header information and the drawing and labeling of the horizontal and vertical axes. Many statements are calls to the CDC 1604 machine subroutines and the programming of these statements will not be discussed here. A detailed discussion of these subroutines can be found in Reference 9.

C. PROGRAM DATAVE

Program DATAVE also utilizes the tape generated by ANTPAT. It calculates average gain and standard deviation of the data points. Similar to TAPPLT, it writes a tape for use with the EAI data plotter.

Figure 11 is a basic block diagram of DATAVE. It consists of three separate parts: the main program, subroutine AVERAGE, and subroutine PLOT.

The main program searches the tape for selected data. AVERAGE then takes repeat runs for a given site, frequency, heading, and polarization and examines them at common values of elevation angles. At these points it calculates their average gain and standard deviation.

1. Average and Standard Deviation

The calculation of average and standard deviation requires that we must work with gain itself and not the logarithm of gain. The statistical analysis can then be performed. Afterwards the average and standard deviations can be converted back to decibels.

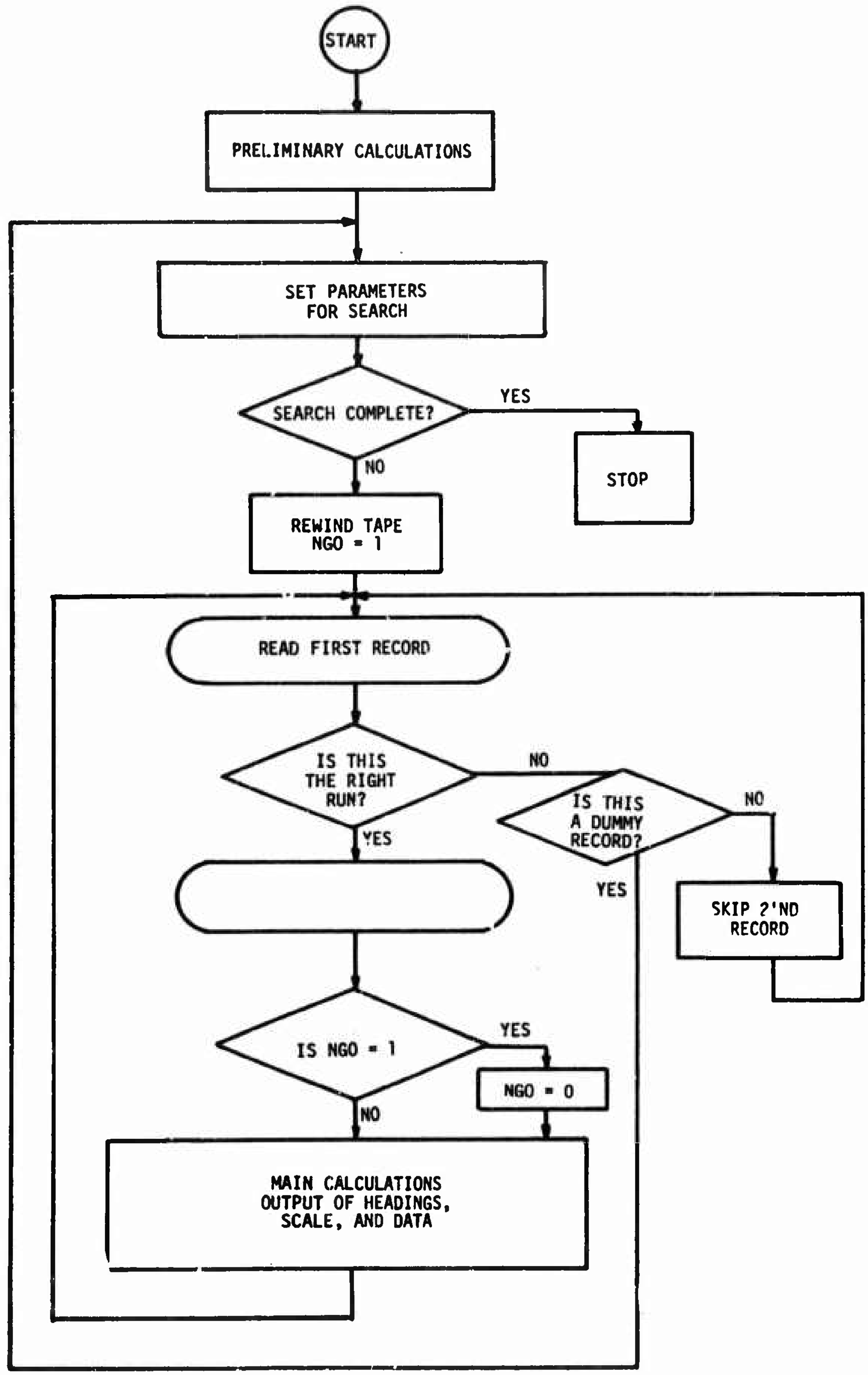


Figure 10. Block Diagram - Program TAPPLT

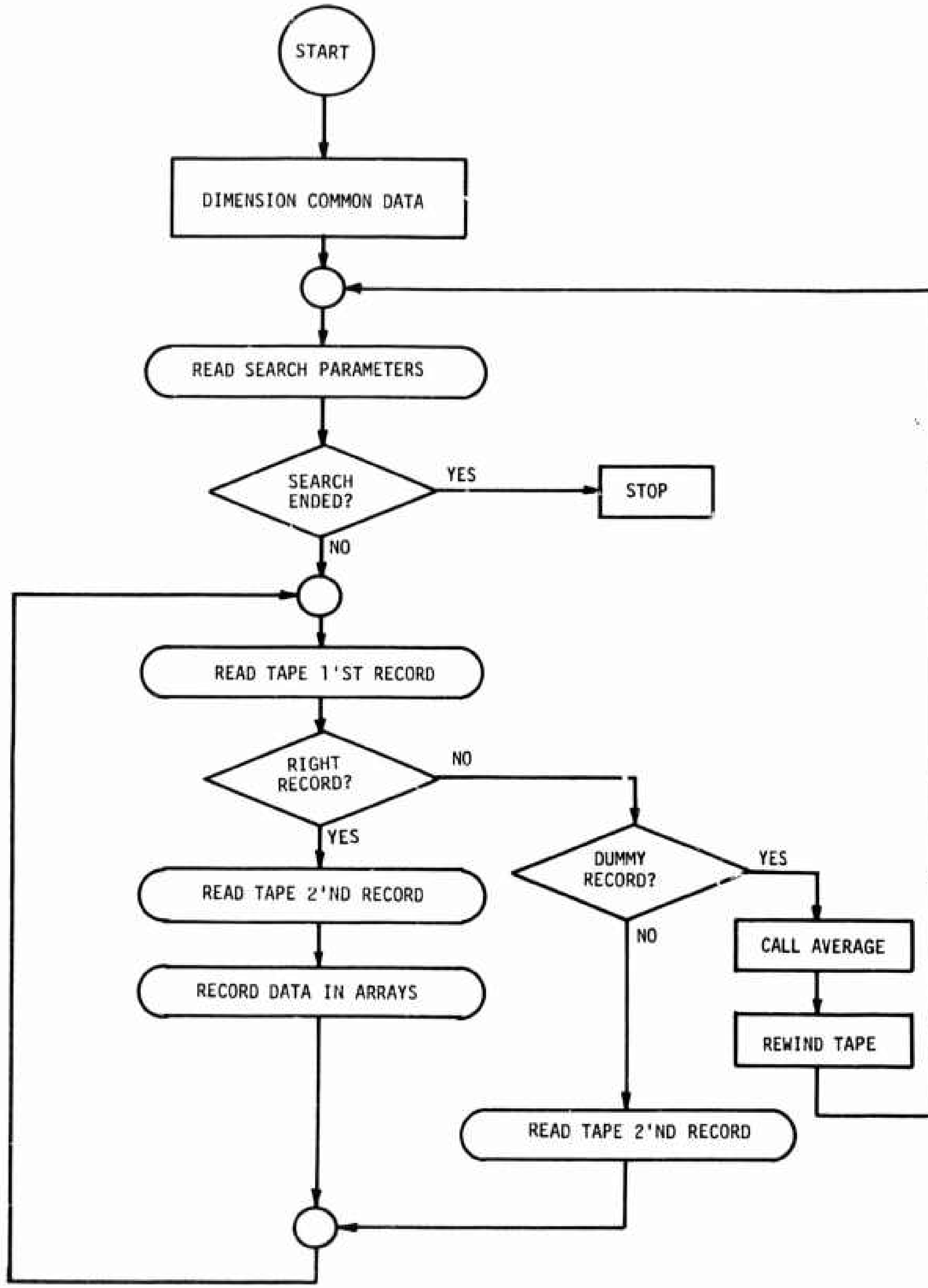


Figure 11. Block Diagram - Program DATAVE Main Program

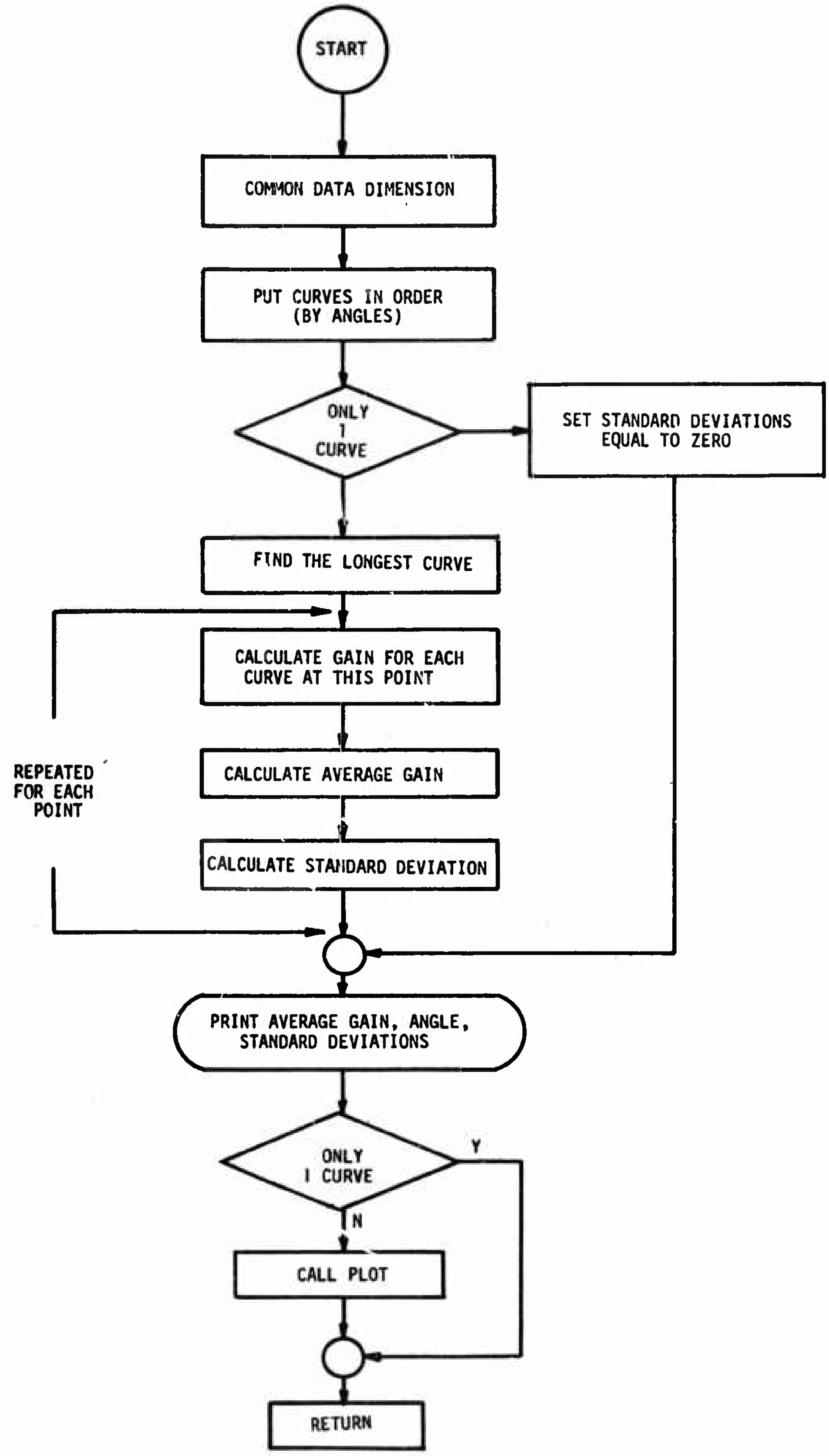


Figure 11. Block Diagram - Program DATAVE Subroutine AVERAGE

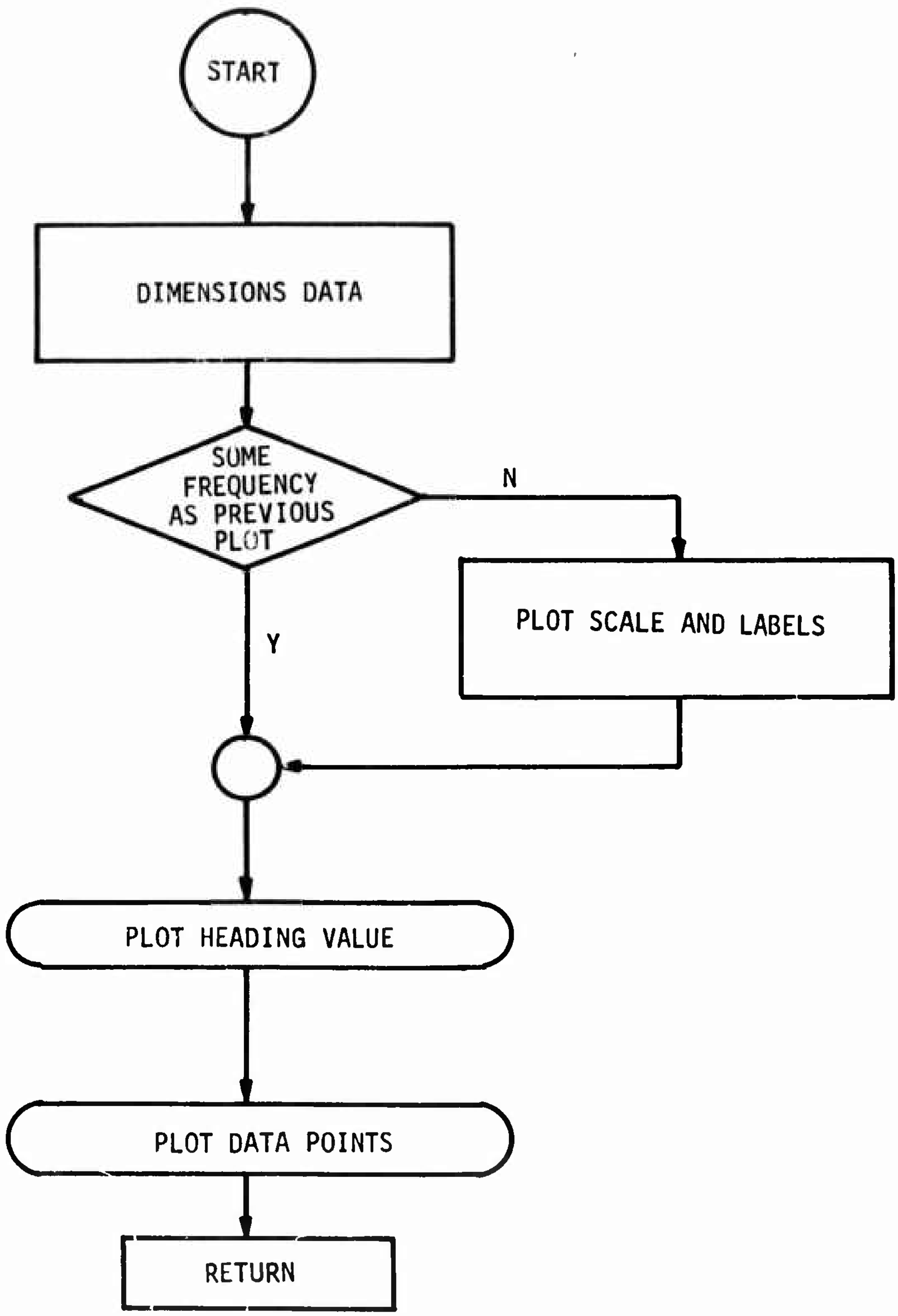


Figure 11. Block Diagram - Program DATAVE Subroutine PLOT

AVERAGE converts the gain data from dB's to multiplicative factors (e.g., 3 dB is converted to 2). The program then calculates the average ($\overline{X}$) and standard deviation (S_x) of these multiplicative factors. The average in db ($\overline{Y}$) is calculated using the relationship:

$$\overline{Y} = 10 \log \overline{X} \cdot \tag{13}$$

The formula for the standard deviation in dB (S_y) can be derived from the definition:

$$S_y^{\,2} = \frac{\sum_{i=1}^{N} (y_i - \overline{y})^2}{N} = \frac{\sum_{i=1}^{N} (\delta y_i)^2}{N} \tag{14}$$

thus

$$S_y^{\,2} = \frac{\sum_{i=1}^{N} \left(\frac{\partial Y}{\partial X} \delta X_i\right)^2}{N} \tag{15}$$

$$S_y^{\,2} = \left(\frac{\partial Y}{\partial X}\right)^2 \frac{\sum_{i=1}^{N} (\delta X_i)^2}{N} \tag{16}$$

but for the dB relationship

$$y = 10 \log X \tag{17}$$

$$\frac{dy}{dx} = \frac{10}{X} \tag{18}$$

therefore we obtain

$$S_y = \frac{10}{\overline{X}} S_x \tag{19}$$

2. Output Form

Subroutine AVERAGE provides a tabulation of the average gain and standard deviation versus elevation angle (see Section VII for an example).

Subroutine PLOT writes a tape for use with the Data Plotter system similar to TAPPLT to obtain plots of average gain versus elevation angle. All headings for a specific frequency and polarization are plotted on the same graph so that the gain as a function of angle off-boresight can be studied easily. An example of this plot can be

found in Section VII. The standard deviation cannot be calculated for azimuths where data was recorded only once. In that case, the standard deviation is set equal to zero and is printed out in tabular form by AVERAGE. Subroutine PLOT plots out the data from the one run.

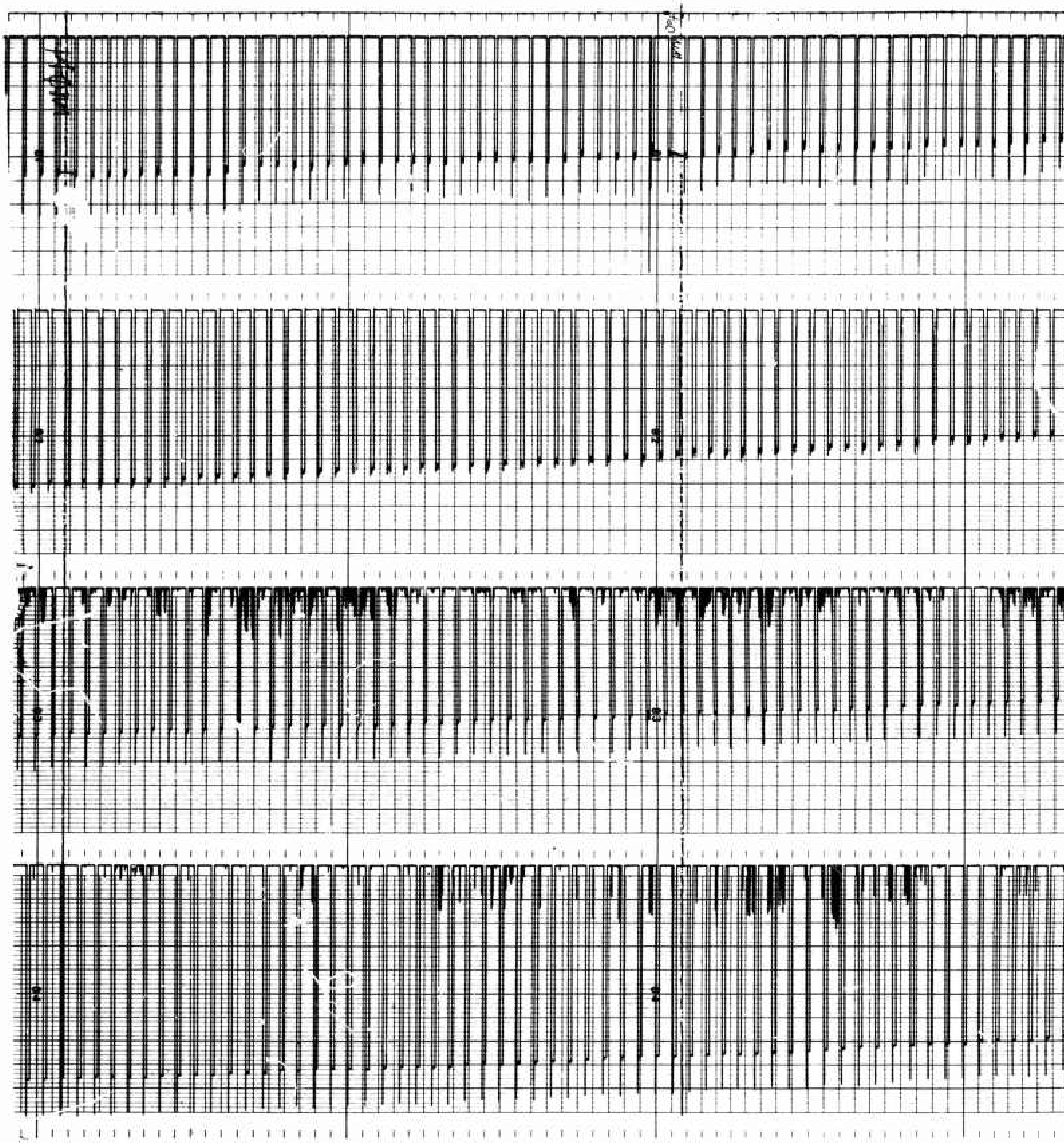
VII. RESULTS

Figure 12 is a sample of the output of the chart recorder. This example is from one of the Iceland boresight runs. The patterns were recorded at 11.401, 30.0, 13.996, and 19.0 MHz. The calibration curves for each frequency are shown at the end of the run. Since the data are smooth (no peaks and nulls), the readings were taken every 10 nmi. In Figure 13 there is a sample of Starr Hill data at frequencies of 11.18, 15.047, 17.983, and 25.335. These curves consist of several peaks and nulls, and for this example, these points were read instead of the 10 nmi points. The data read from these plots are placed on data sheets (Figure 14). For each frequency on each run there is a column for ground distance (NM), divisions on the chart (DIV), and attenuation in the circuit (dB). There is also at least one calibration curve for each frequency. In most cases calibration curves were run both before and after the run.

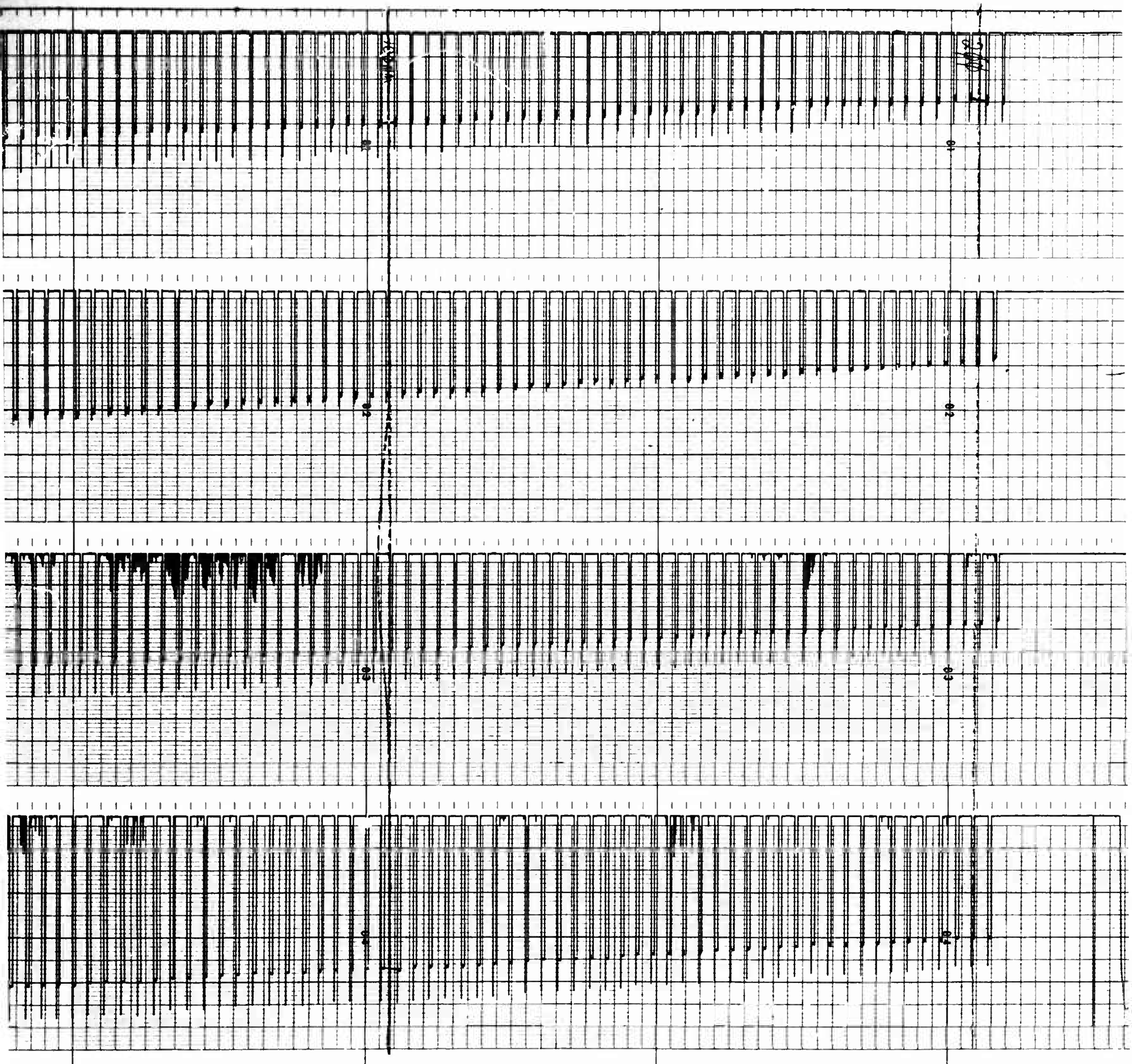
These data are punched on computer cards and serve as input to the ANTPAT program. This program, which was discussed in Section VI, has two outputs: (1) a printout, and (2) a data tape. A sample of the printout (Figure 15) lists the elevation angle (degrees), the range (nmi), the power at the receiver (dB), attenuation in the circuit (dB), the received signal (dB), the free space loss (dB), antenna gain (dB), and the loop gain (dB) in columns 1 through 8 respectively. In this and all of the figures of this section the loop gain has been set to zero (see Section V) and therefore the data represents only relative gain. The magnetic tape output was used for further analysis of the data.

A typical plot from Program TAPPLT of data from the Panama antenna is shown in Figure 16. The two curves are plots of different runs on the same frequency and the same azimuth and hence represent data from two printouts like the above. The number after the identifying mark is the date of the run. The flight plan called for data runs on boresight, ±5 degrees from boresight and ±10 degrees from boresight with repeats on the boresight and ±10 degree runs. This plan was followed almost completely in Panama flights.

The average and standard deviation of all runs on the same azimuth and frequency were calculated using the DATAVE Program. The outputs of this program include both a printout and a plot. The printout (Figure 17) lists the average (dB), elevation angle (deg), standard deviation (dB), and the number of points. The number of points is given so that we may assign some confidence to the value of the standard deviation. Figure 18 shows the average of the curves in Figure 16. Average curves of the Panama antenna were plotted for each frequency and heading. Figures 19 through 26 show the averages on boresight and ±10 degrees from boresight. The ±5 degree azimuths are omitted for clarity of presentation. It will be noticed that the



A



BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND OHIO PRINTED IN U.S.A.

B

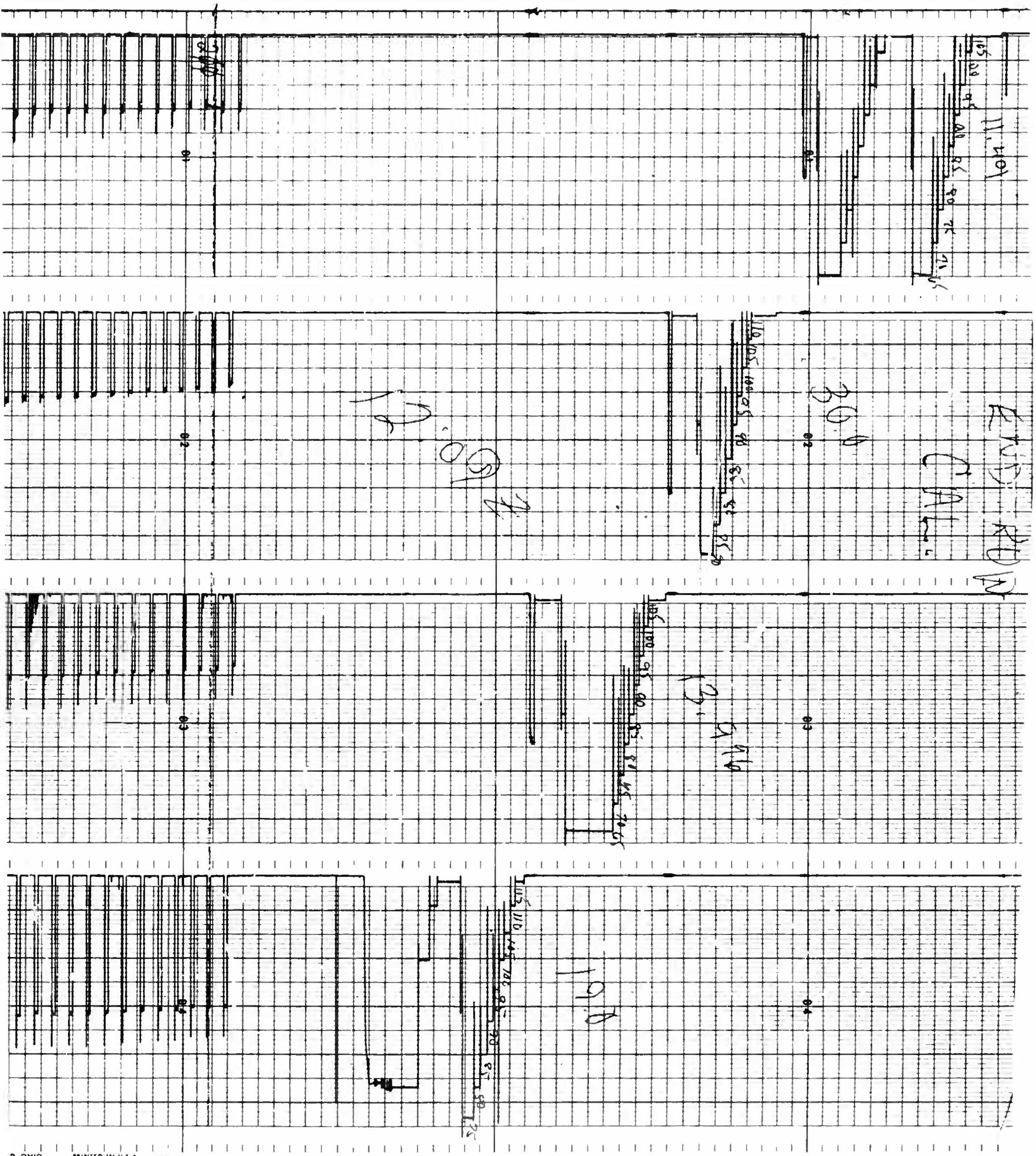
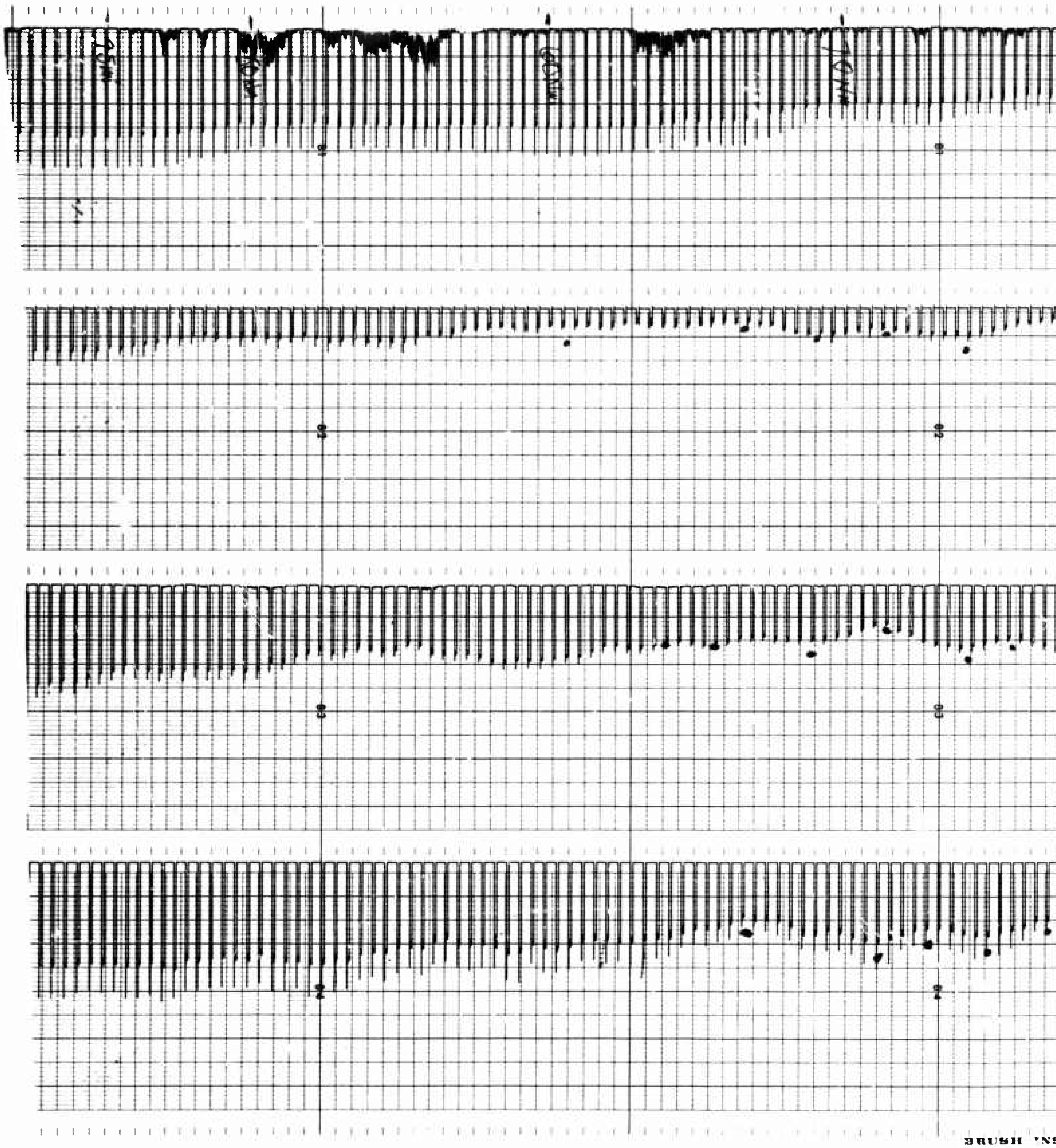
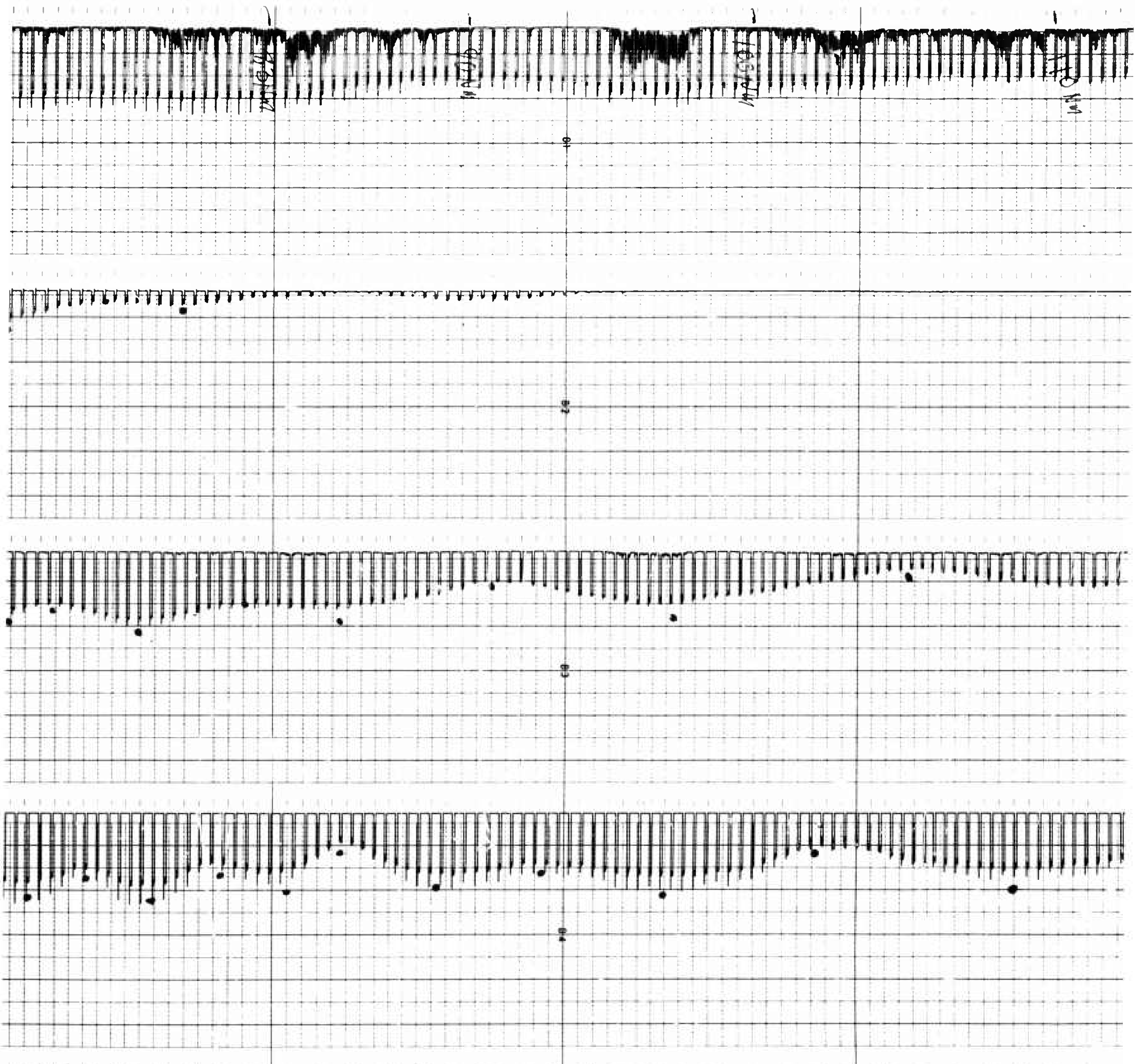


Figure 12. Chart Recorder Output - Iceland



A



BRUSH INSTRUMENTS DIVISION OF CLEVITE CORPORATION CLEVELAND OHIO PRINTED IN U.S.A

B

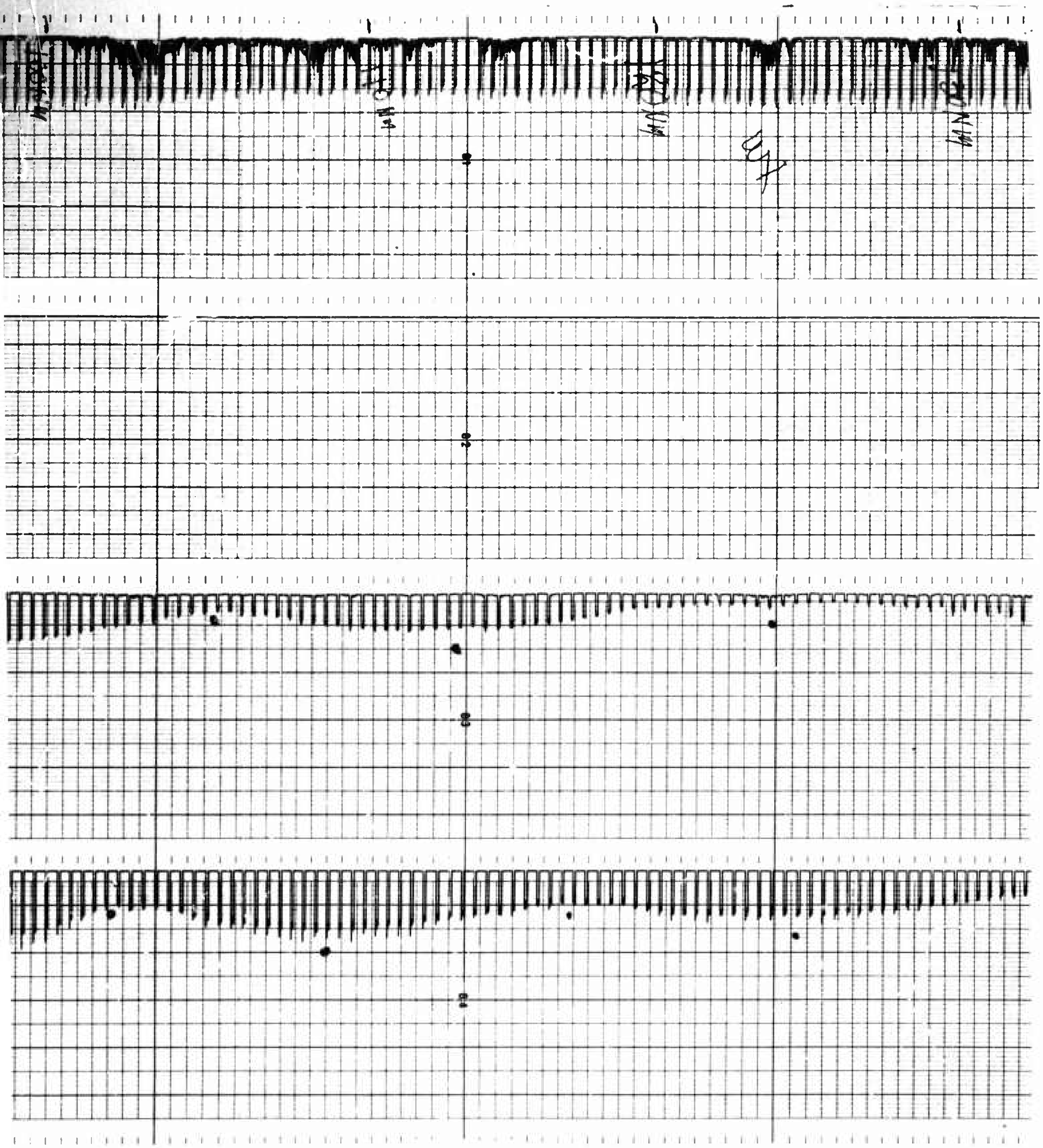
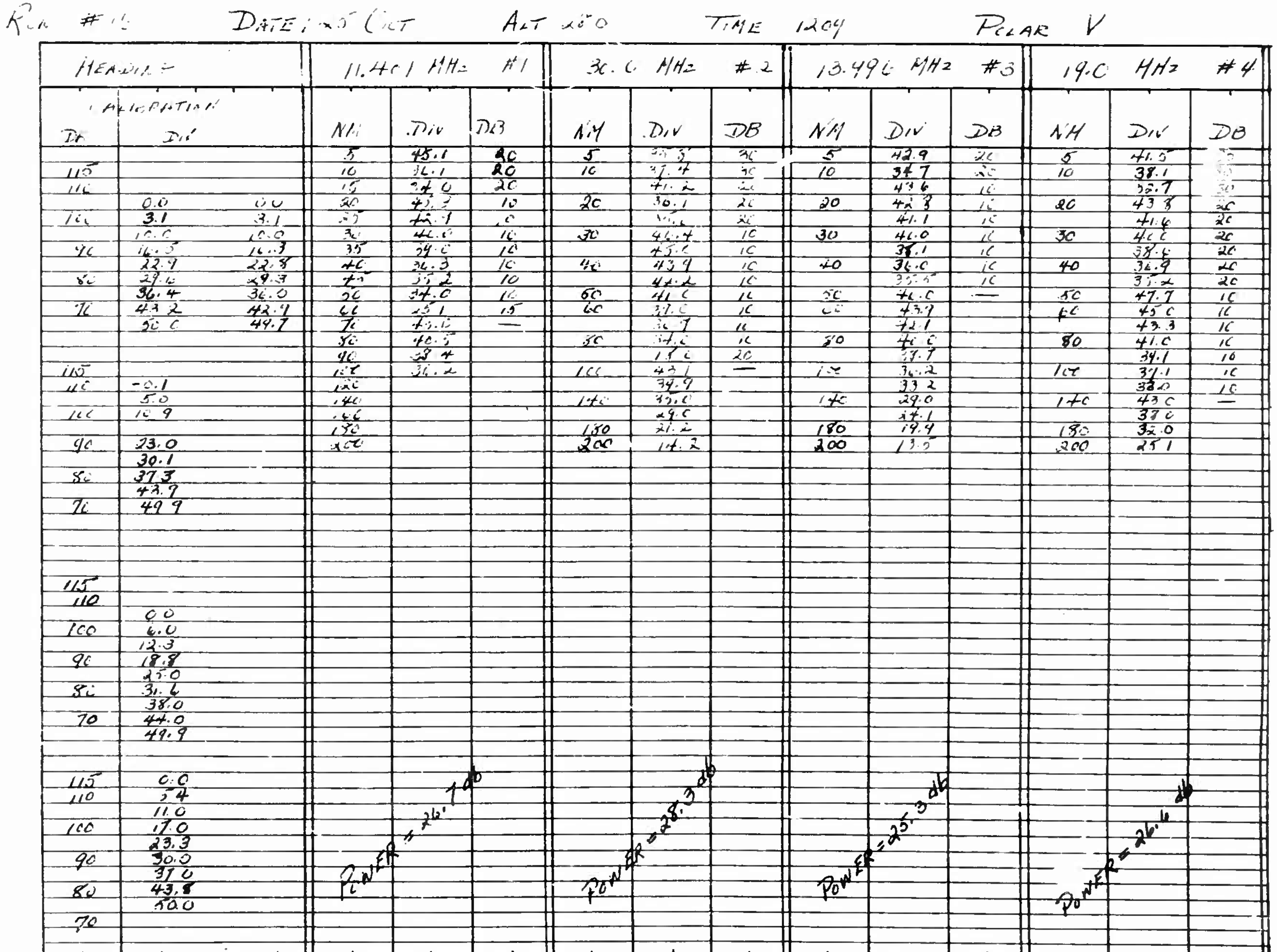


Figure 13. Chart Recorder Output - Starr Hill



RUN #[illegible] DATE [illegible] OCT ALT 2[illegible]0 TIME 1204 POLAR V

HEADING			11.401 MHz #1			30.0 MHz #2			13.496 MHz #3			19.0 MHz #4		
CALIBRATION DF	DIV		NM	DIV	DB	NM	DIV	DB	NM	DIV	DB	NH	DIV	DB
			5	45.1	20	5	[illegible]	30	5	42.9	20	5	41.5	[illegible]
115			10	36.1	20	10	37.4	30	10	34.7	20	10	38.1	[illegible]
110			15	24.0	20		41.2	20		43.6	10		35.7	30
	0.0	0.0	20	43.3	10	20	30.1	20	20	42.3	10	20	43.8	20
100	3.1	3.1	25	42.1	10		[illegible]	20		41.1	10		41.6	20
	10.0	10.0	30	44.0	10	30	46.4	10	30	46.0	10	30	46.0	20
90	16.5	16.3	35	39.0	10		45.0	10		38.1	10		38.6	20
	22.9	22.8	40	36.3	10	40	43.9	10	40	36.0	10	40	36.9	20
80	29.6	29.3	45	35.2	10		44.2	10		35.5	10		35.2	20
	36.4	36.0	50	34.0	10	60	41.0	10	50	46.0	—	50	47.7	10
70	43.2	42.9	60	25.1	15	60	37.0	10	60	43.9		60	45.0	10
	50.0	49.7	70	43.0	—		36.7	10		42.1			43.3	10
			80	40.5		80	34.0	10	80	40.0		80	41.0	10
			90	38.4			18.0	20		37.7			34.1	10
115			100	36.2		100	43.1	—	100	36.2		100	37.1	10
110	-0.1		120				34.9			33.2			38.0	10
	5.0		140			140	39.0		140	29.0		140	43.0	—
100	10.9		160				29.0			24.1			37.0	
			180			180	21.2		180	19.4		180	32.0	
90	23.0		200			200	14.2		200	13.5		200	25.1	
	30.1													
80	37.3													
	43.7													
70	49.9													
115														
110														
	0.0													
100	6.0													
	12.3													
90	18.8													
	25.0													
80	31.6													
	38.0													
70	44.0													
	49.9													
115	0.0													
110	5.4													
	11.0													
100	17.0													
	23.3													
90	30.0													
	37.0													
80	43.8													
	50.0													
70														

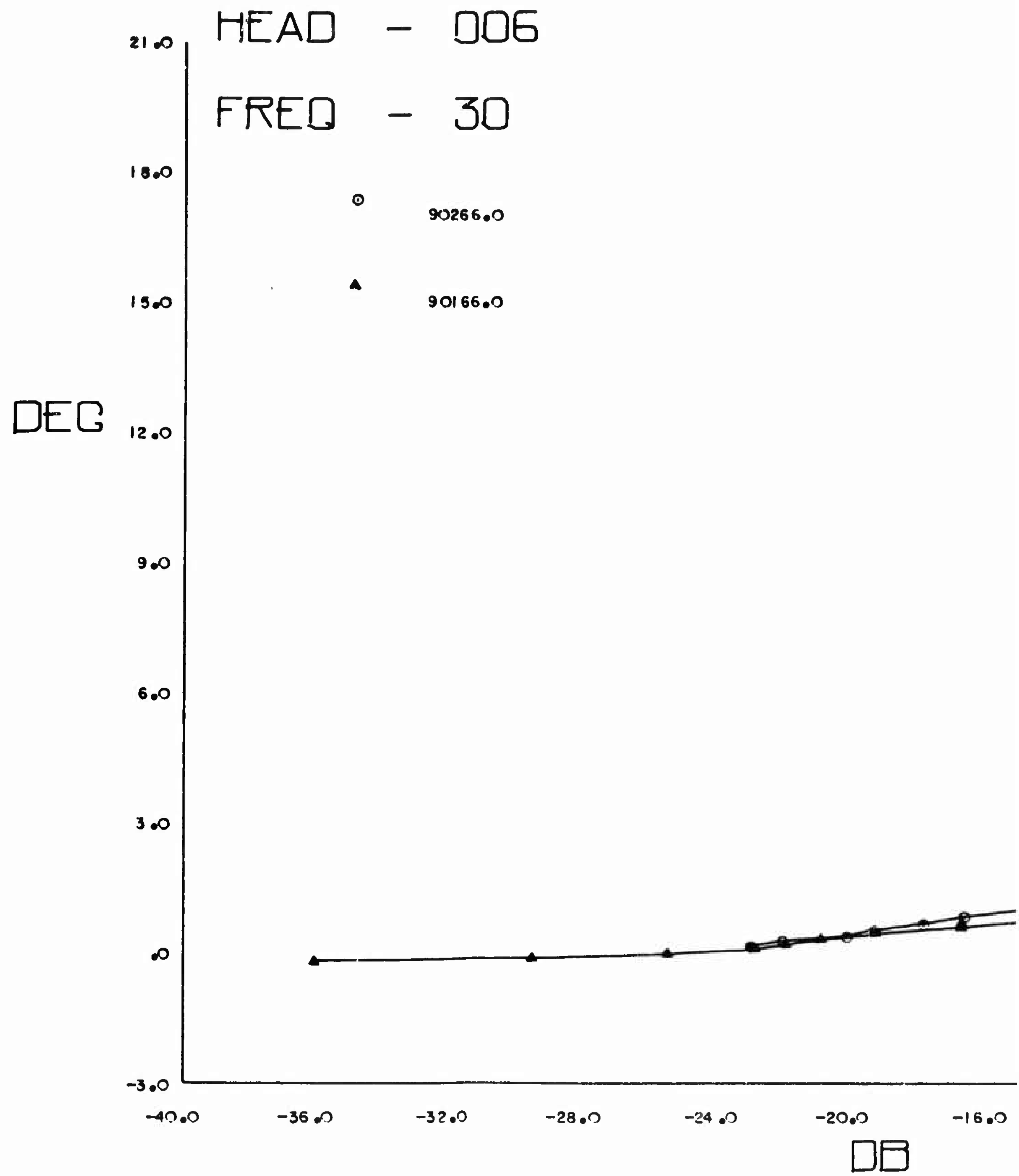
POWER = 26.7 db POWER = 28.3 db POWER = 25.3 db POWER = 26.6 db

Figure 14. Typical Data Sheet

FREQUENCY= 30.0000MCS TRUE HEADING 6 RUN NO. 3
RECEIVER 4 ALTITUDE 30.0KFEET DATE 90166 TIME 1200 POWER= 26.70DB POL= -4

ANGLE	RANGE	DB	ATTEN	SIGNAL	SPACE LOSS	SIGNAL STRENGTH	LOOP GAIN
-.17	240.00	124.33	-0	124.33	114.95	-36.08	0
-.06	230.00	117.80	-0	117.80	114.58	-29.62	0
.03	221.00	113.16	-0	113.16	114.24	-25.62	0
.15	210.00	110.09	-0	110.09	113.79	-23.00	0
.26	200.00	108.69	-0	108.69	113.37	-22.02	0
.38	190.00	107.17	-0	107.17	112.93	-20.94	0
.51	180.00	105.05	-0	105.05	112.46	-19.29	0
.66	170.00	102.14	-0	102.14	111.96	-16.38	0
.82	160.00	104.05	5.00	99.05	111.43	-14.32	0
1.00	150.00	102.03	5.00	97.03	110.87	-13.76	0
1.18	140.00	101.19	5.00	96.19	110.28	-12.62	0
1.39	130.00	103.61	10.00	93.61	109.63	-10.67	0
1.63	120.00	101.58	10.00	91.58	108.94	-9.34	0
1.87	111.00	105.10	15.00	90.10	108.26	-8.53	0
2.58	90.00	105.57	20.00	85.57	106.45	-5.83	0
3.03	80.00	103.54	20.00	83.54	105.43	-4.81	0
3.59	70.00	101.81	20.00	81.81	104.27	-4.23	0
4.32	60.00	105.38	25.00	80.38	102.94	-4.14	0
5.32	50.00	103.50	25.00	78.50	101.37	-3.83	0
6.78	40.00	106.32	30.00	76.32	99.46	-3.56	0
9.14	30.00	103.61	30.00	73.61	97.01	-3.30	0
13.71	20.00	102.38	35.00	67.38	93.63	-.43	0
16.03	17.00	101.19	35.00	66.19	92.31	-.59	0
18.07	15.00	101.71	35.00	66.71	91.32	-2.09	0
22.24	12.00	105.81	40.00	65.81	89.61	-2.90	0
26.16	10.00	105.19	40.00	65.19	88.29	-3.60	0
44.56	5.00	105.67	35.00	70.67	84.28	-13.09	0

Figure 15. Program ANTPAT - Tabular Output - Panama


HEAD - 006
FREQ - 30
90266.0
90166.0
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
DB

A

PAN-V

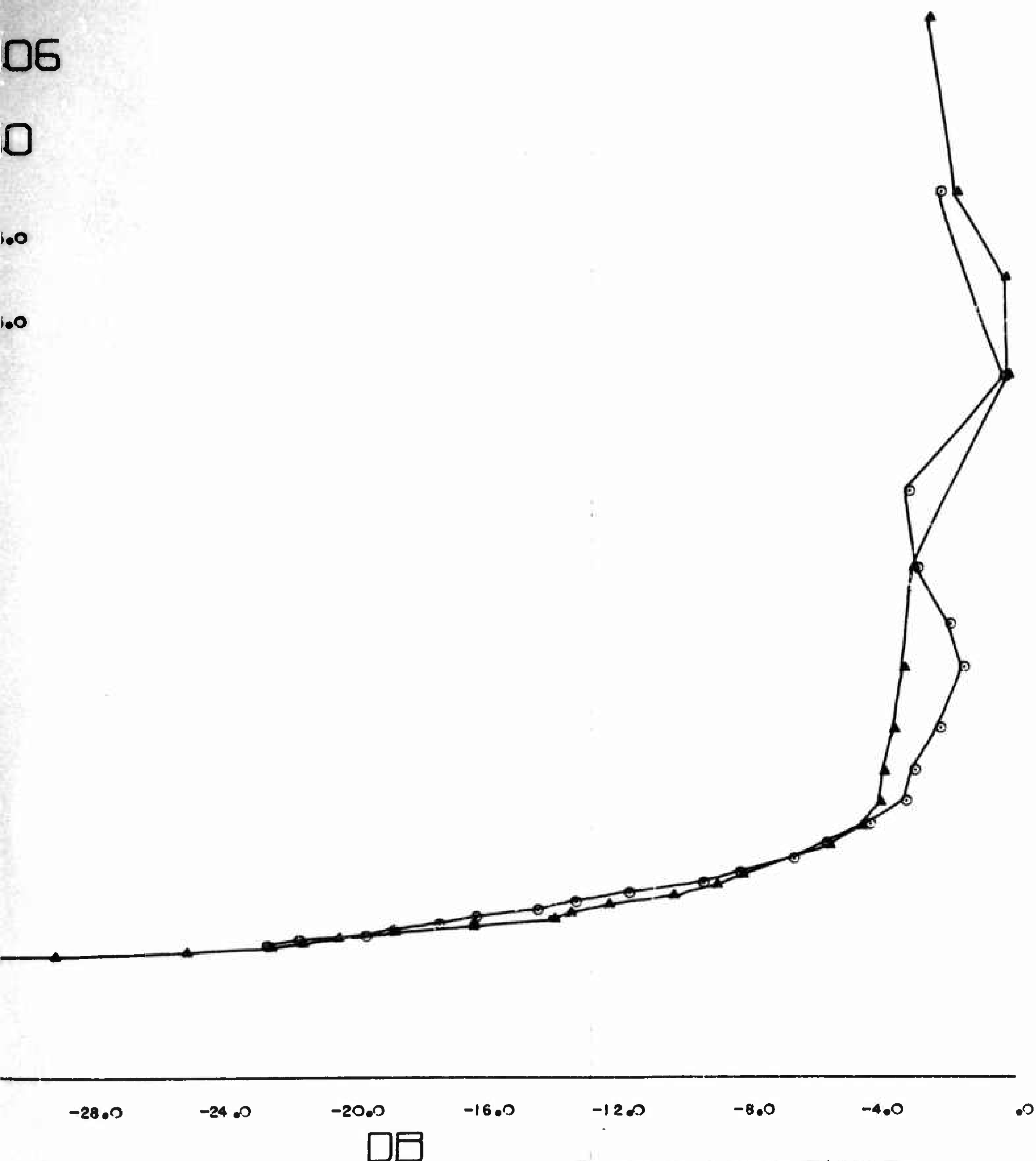


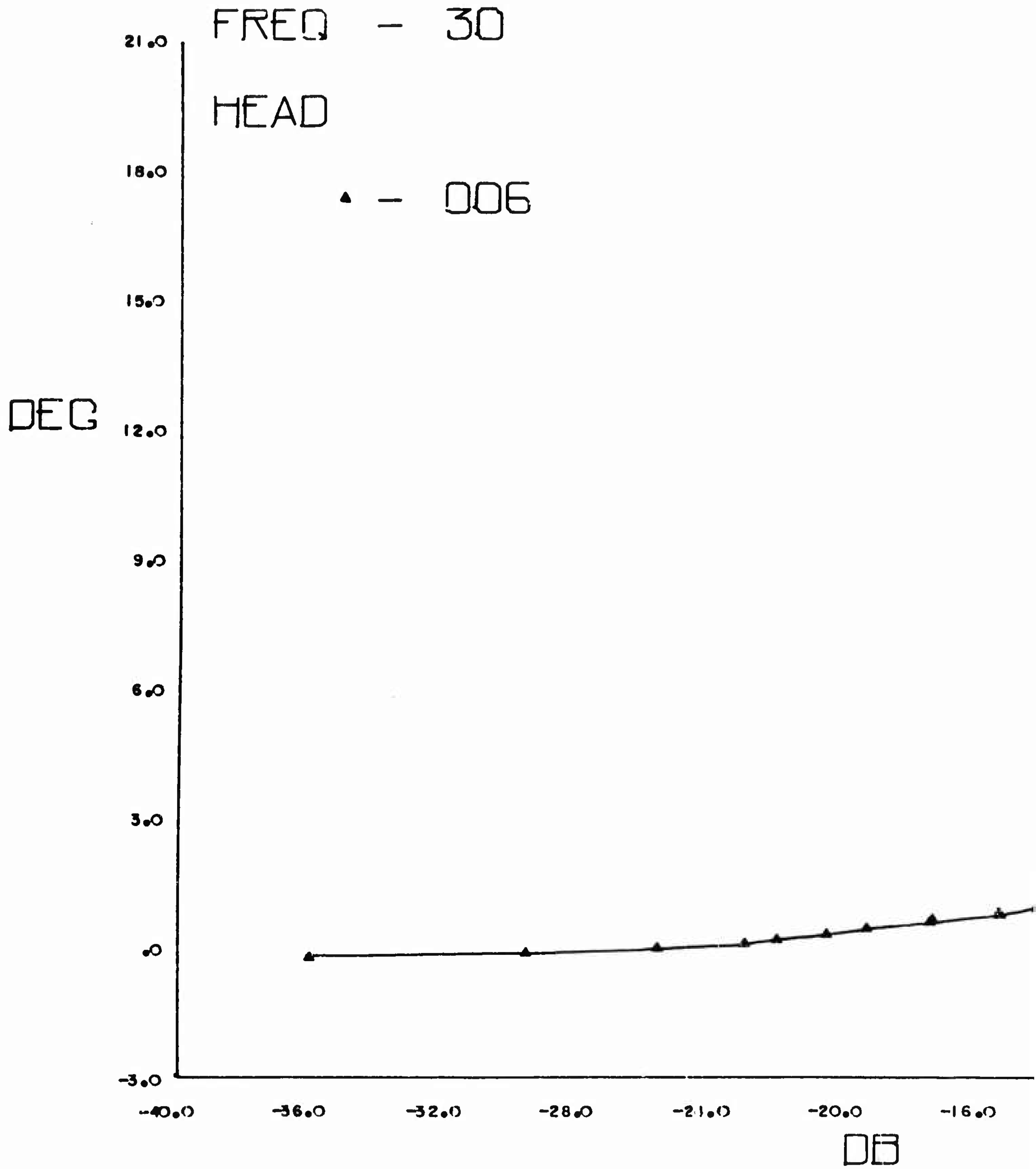
Figure 16 - Program TAPPLT - Plot Output (Panama)

B

FREQUENCY= 30 POLARIZATION NO. 5 ANGLE= 6

AVE GAIN	ANGLE	STD.DEV.	POINTS
-36.0801	-.1653	0	1
-29.6162	-.0646	0	1
-25.6206	.0291	0	1
-23.1000	.1480	.1045	2
-22.1159	.2608	.1003	2
-20.5949	.3789	.3327	2
-19.3517	.5111	.0610	2
-17.4197	.6620	.5776	2
-15.4039	.8228	1.2369	2
-14.3018	.9955	.5810	2
-13.1356	1.1826	.5502	2
-11.3356	1.3920	.7149	2
-9.6034	1.6322	.2700	2
-8.6331	1.8737	.1024	2
-5.9066	2.5834	.0822	2
-4.7304	3.0292	.0778	2
-3.8780	3.5929	.3423	2
-3.7048	4.3243	.4142	2
-3.1479	5.3211	.6312	2
-2.5884	6.7769	.8709	2
-3.2464	9.1423	.0536	2
-.5137	13.7134	.0603	2
-1.0781	16.0317	.5221	2
-2.3234	18.0703	.2361	2
-2.8997	22.2359	0	1

Figure 17. Program - DATAVE - Output (Panama)


FREQ - 30
HEAD
- 006
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-20.0
-16.0
DB

PAN-V

A

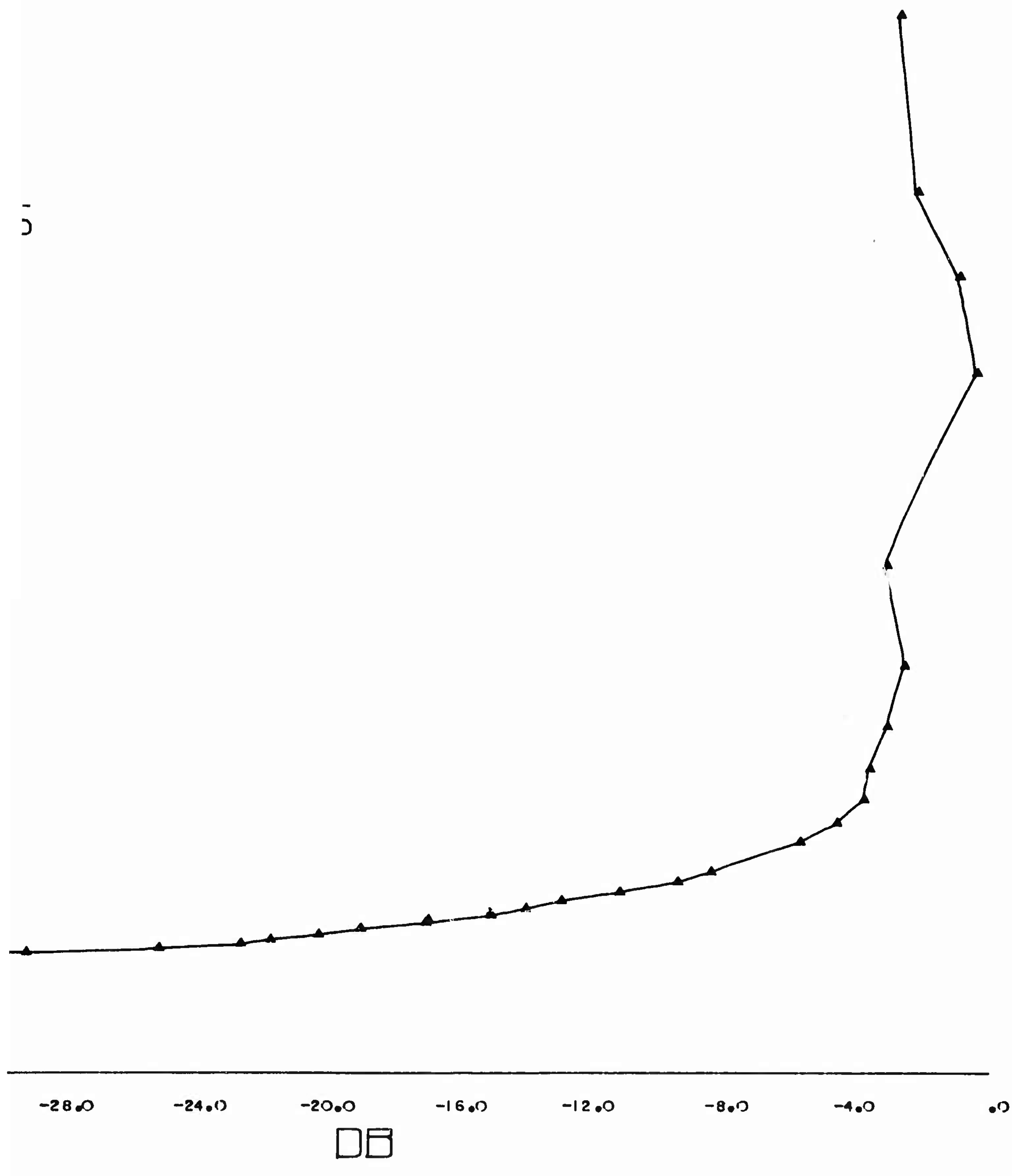


Figure 18. Program DATAVE -
Plot Output (Panama)

B

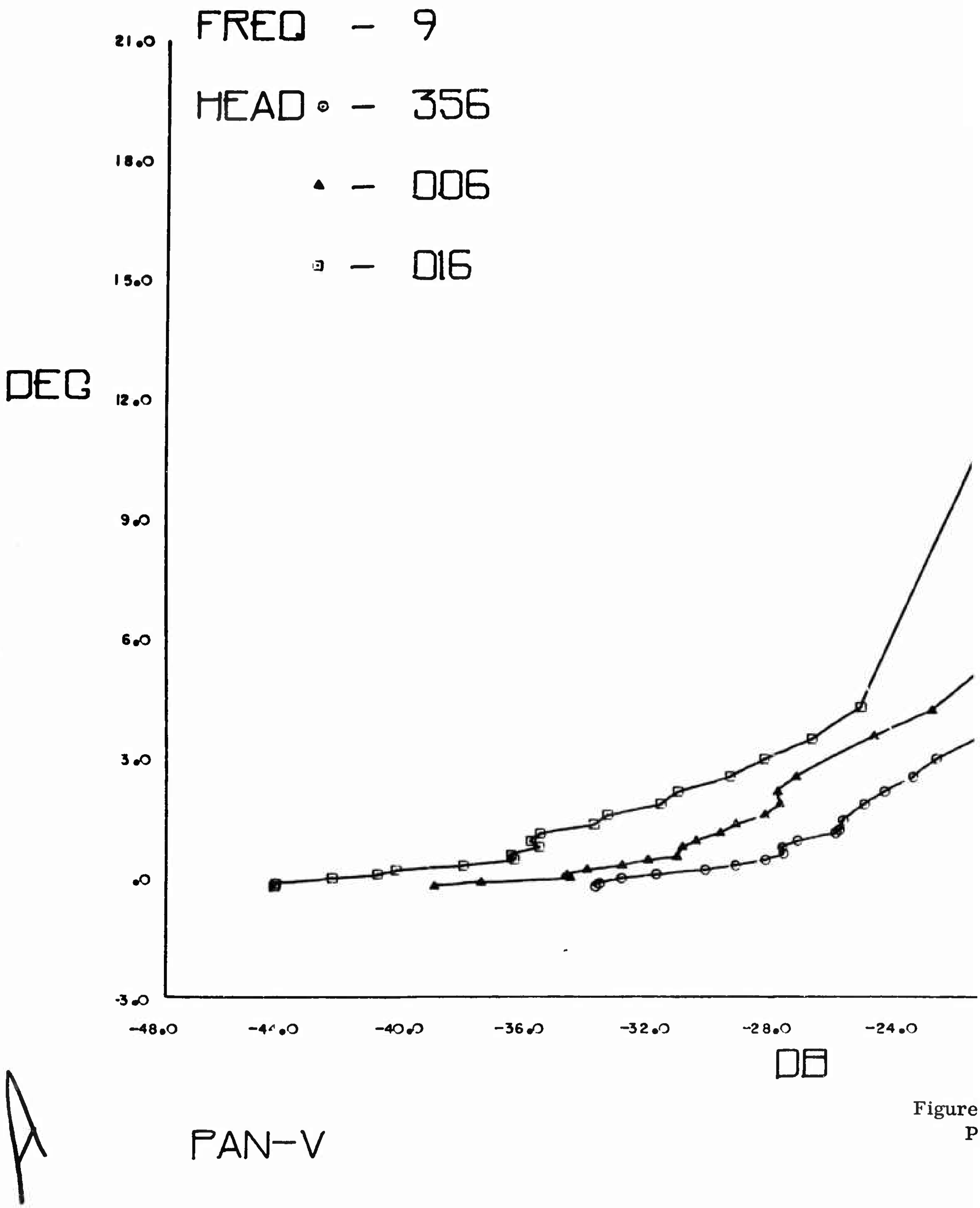

FREQ - 9
HEAD - 356
- 006
- 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-48.0
-40.0
-36.0
-32.0
-28.0
-24.0
DB
PAN-V

Figure
P

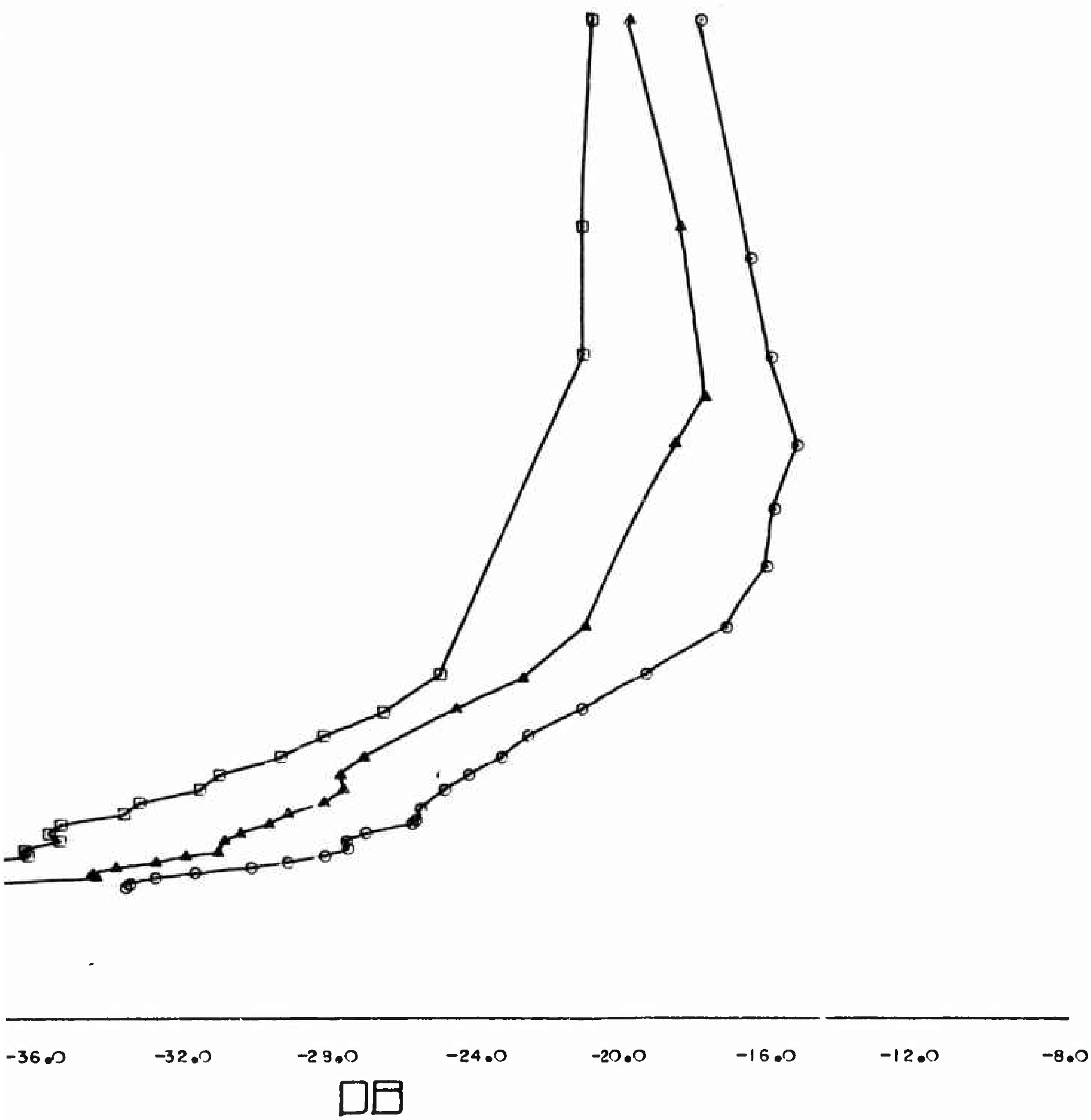
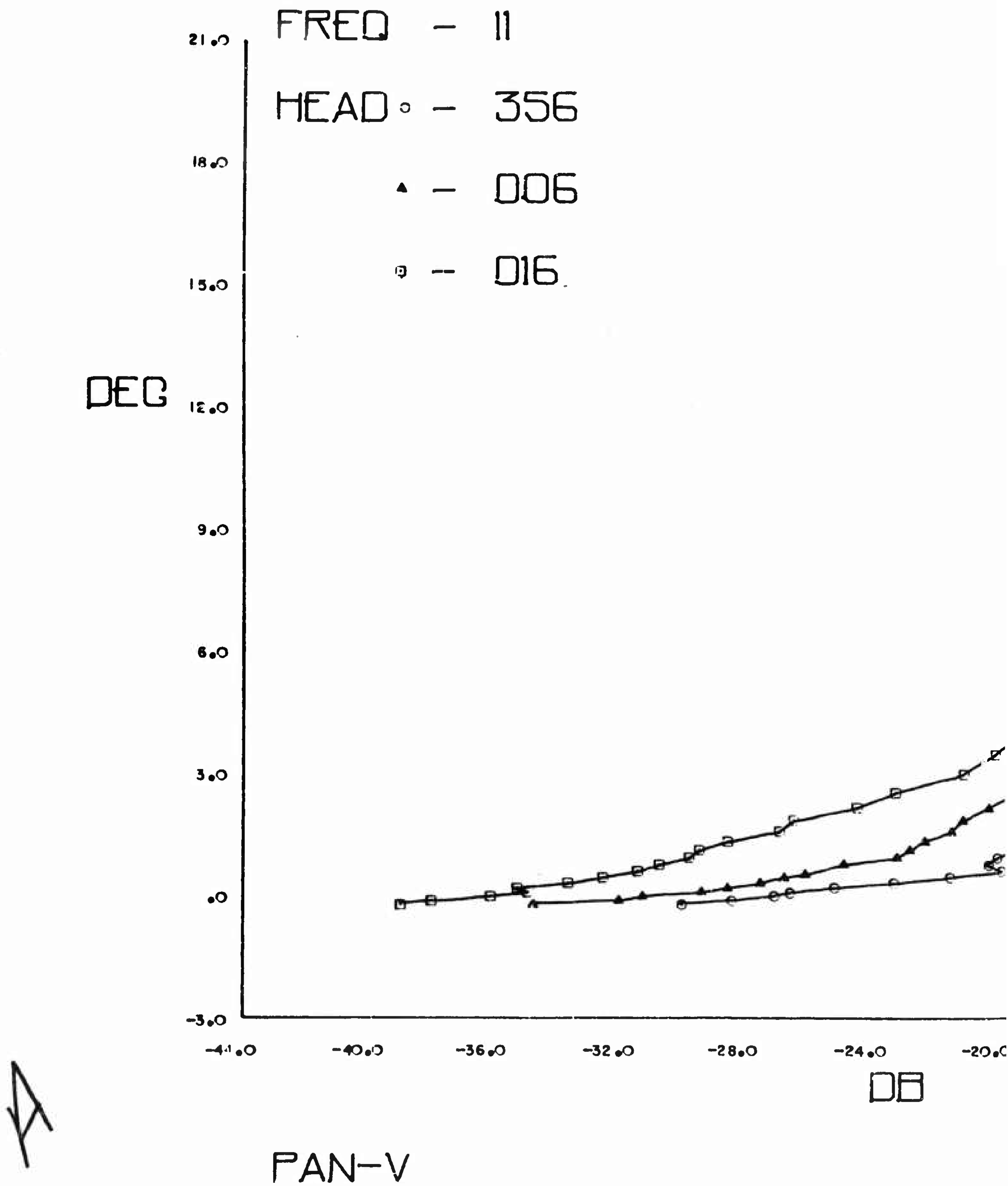


Figure 19. Panama Antenna Patterns - 9 MHz

B


FREQ – 11
HEAD ○ – 356
▲ – 006
□ – 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
PAN-V

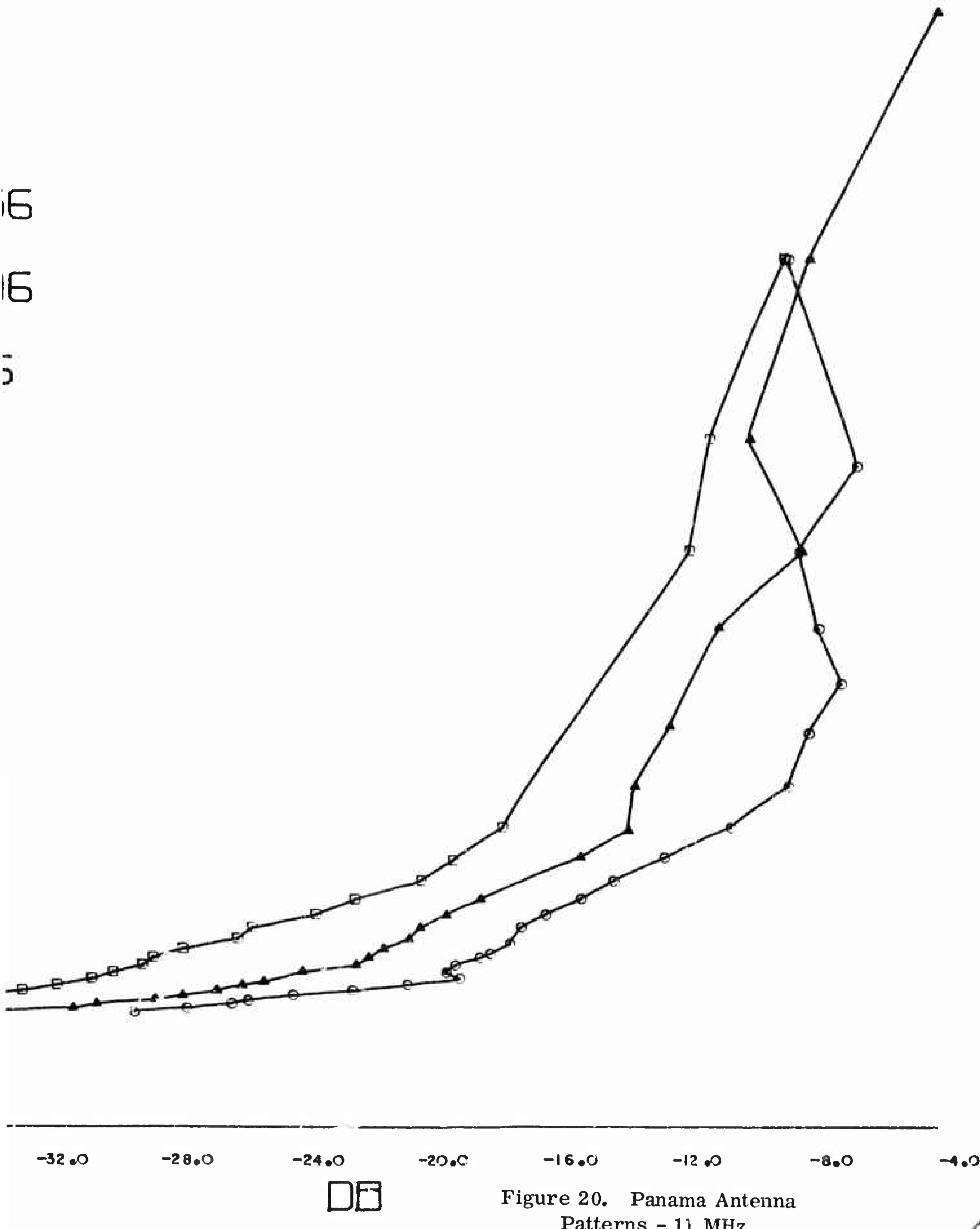
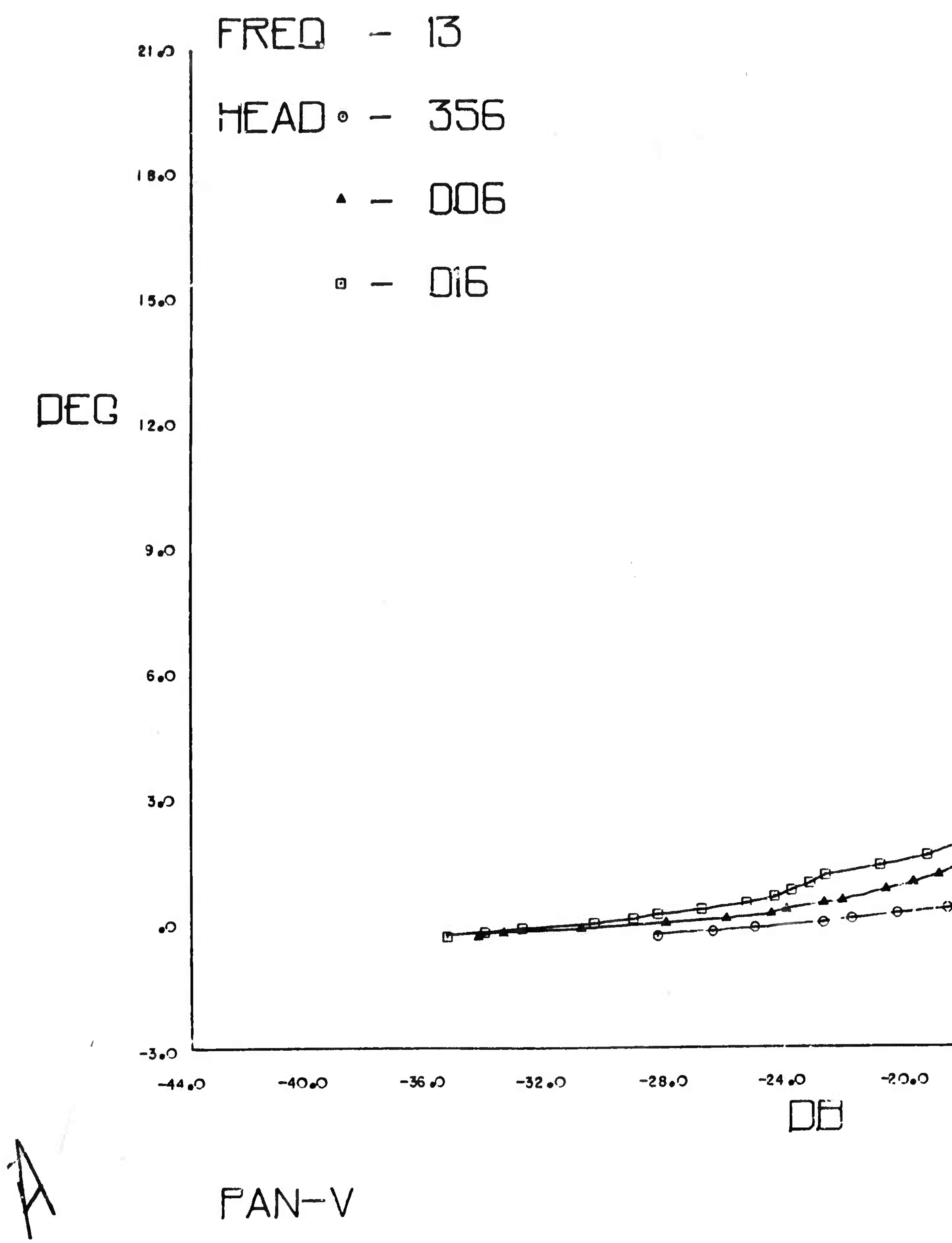


Figure 20. Panama Antenna Patterns - 11 MHz

B


FREQ - 13
HEAD ∘ - 356
▲ - 006
▫ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
A
PAN-V

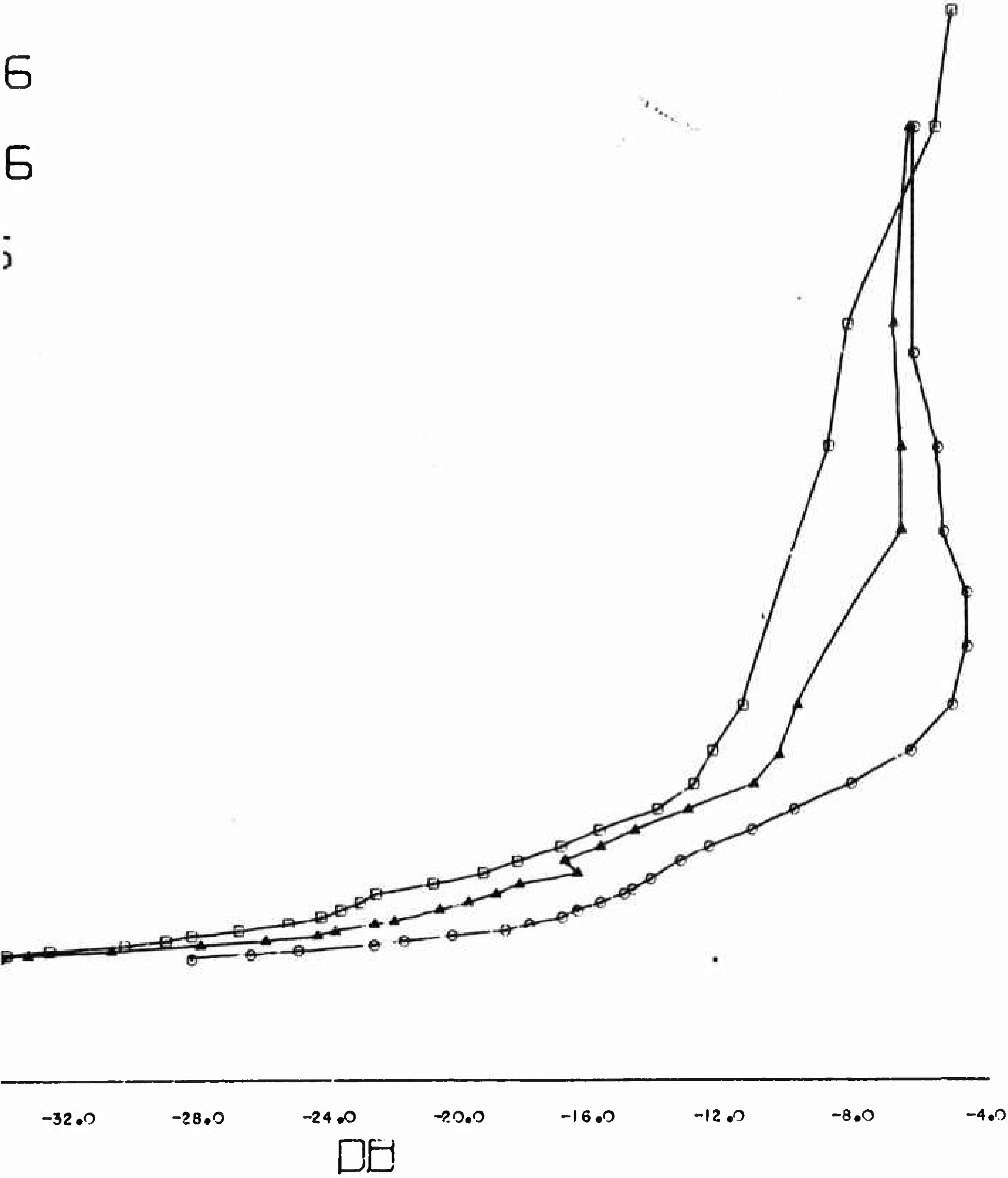
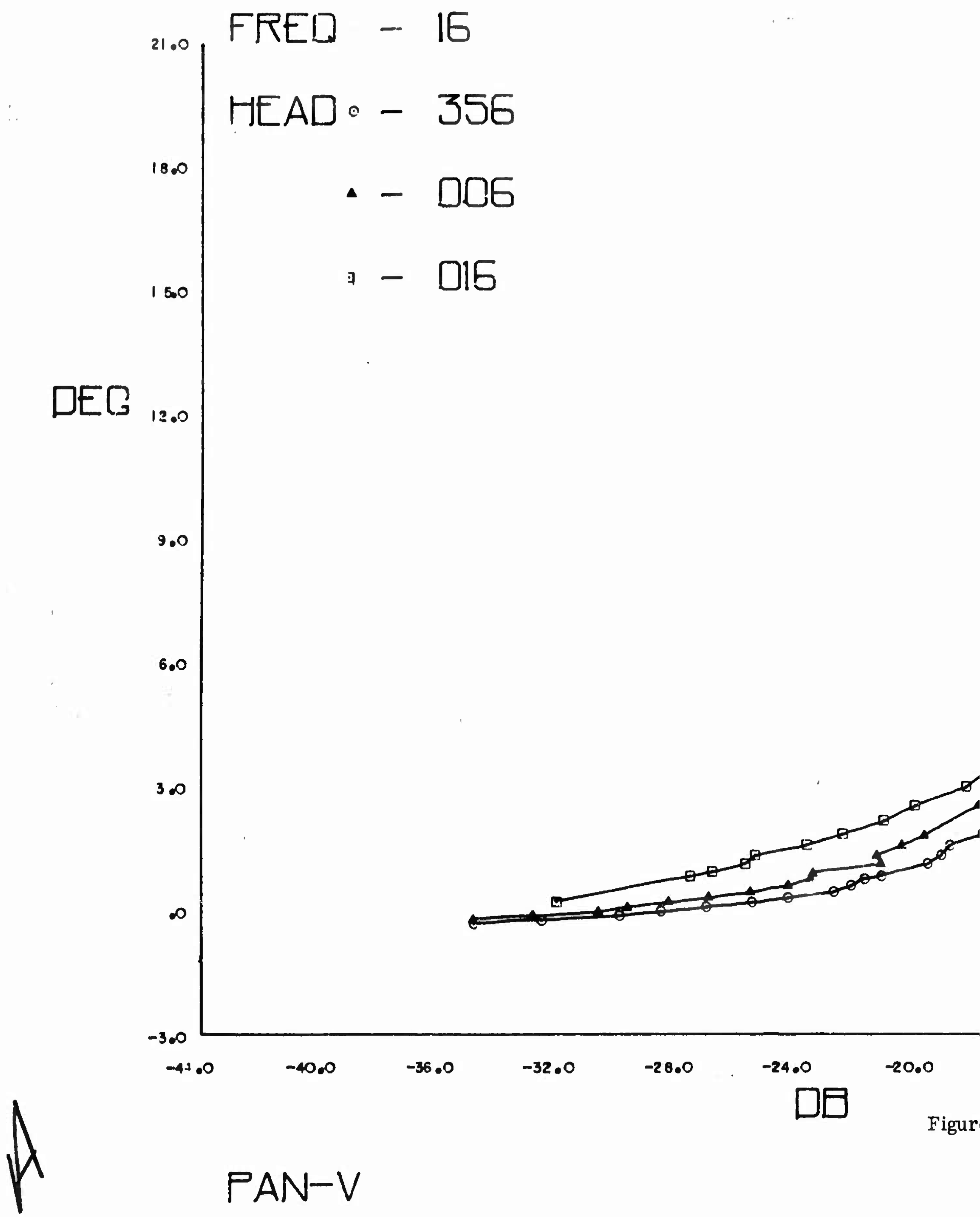


Figure 21. Panama Antenna
Patterns - 13 MHz

B


FREQ - 16
HEAD ○ - 356
▲ - 006
□ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
PAN-V

Figur

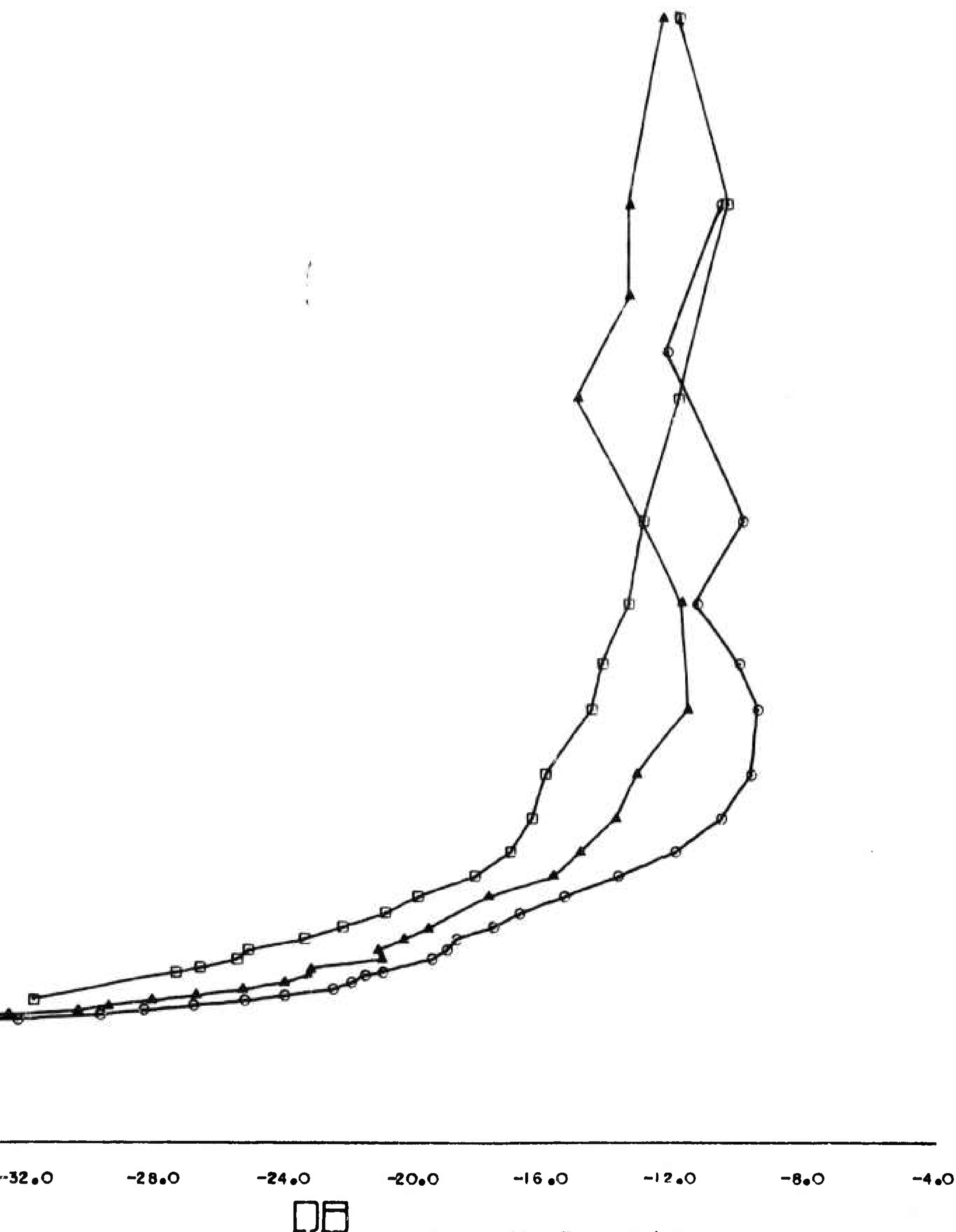
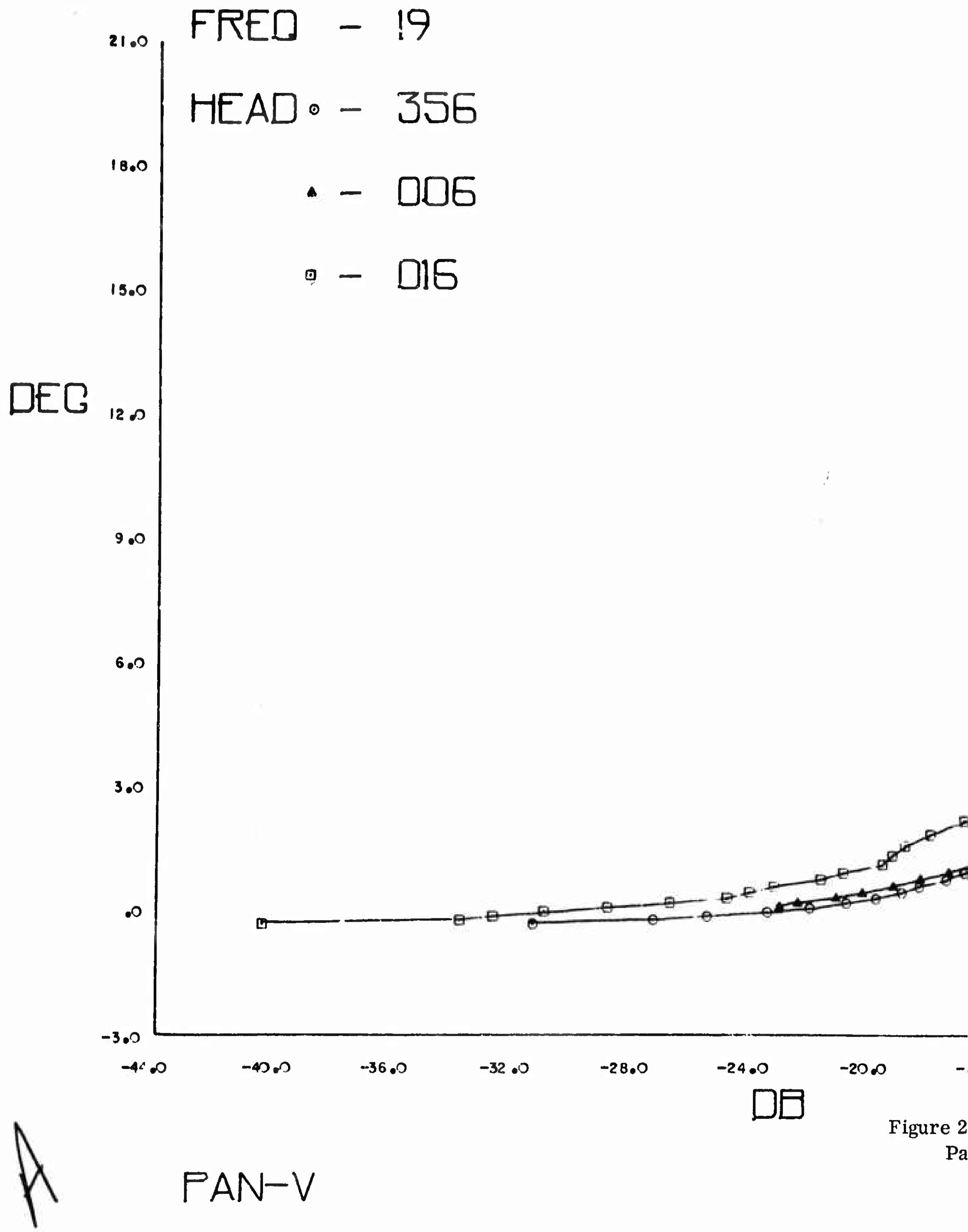


Figure 22. Panama Antenna Patterns - 16 MHz

B



FREQ - 19
HEAD ⊙ - 356
▲ - 006
⊡ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
PAN-V

Figure 2
Pa

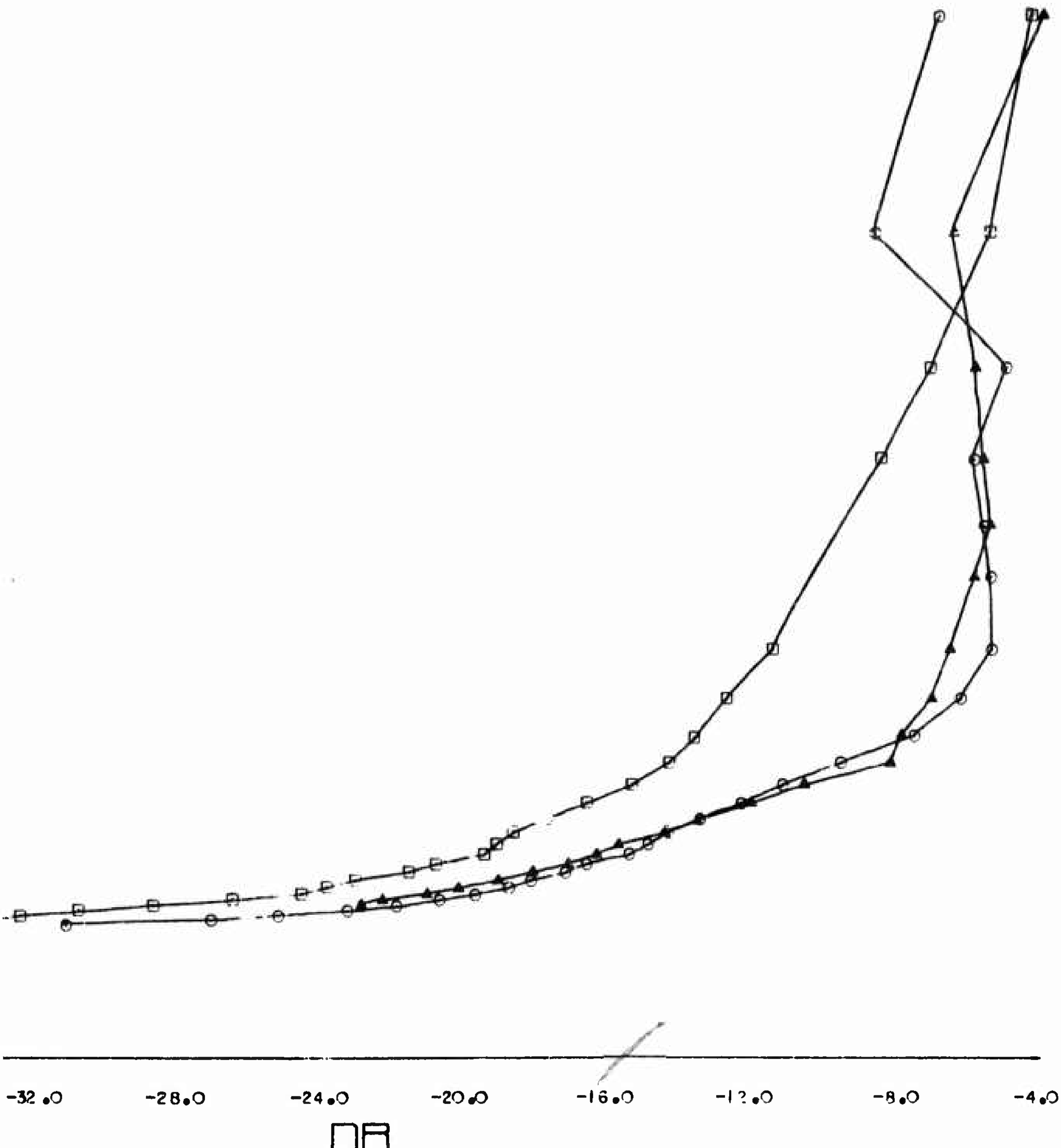
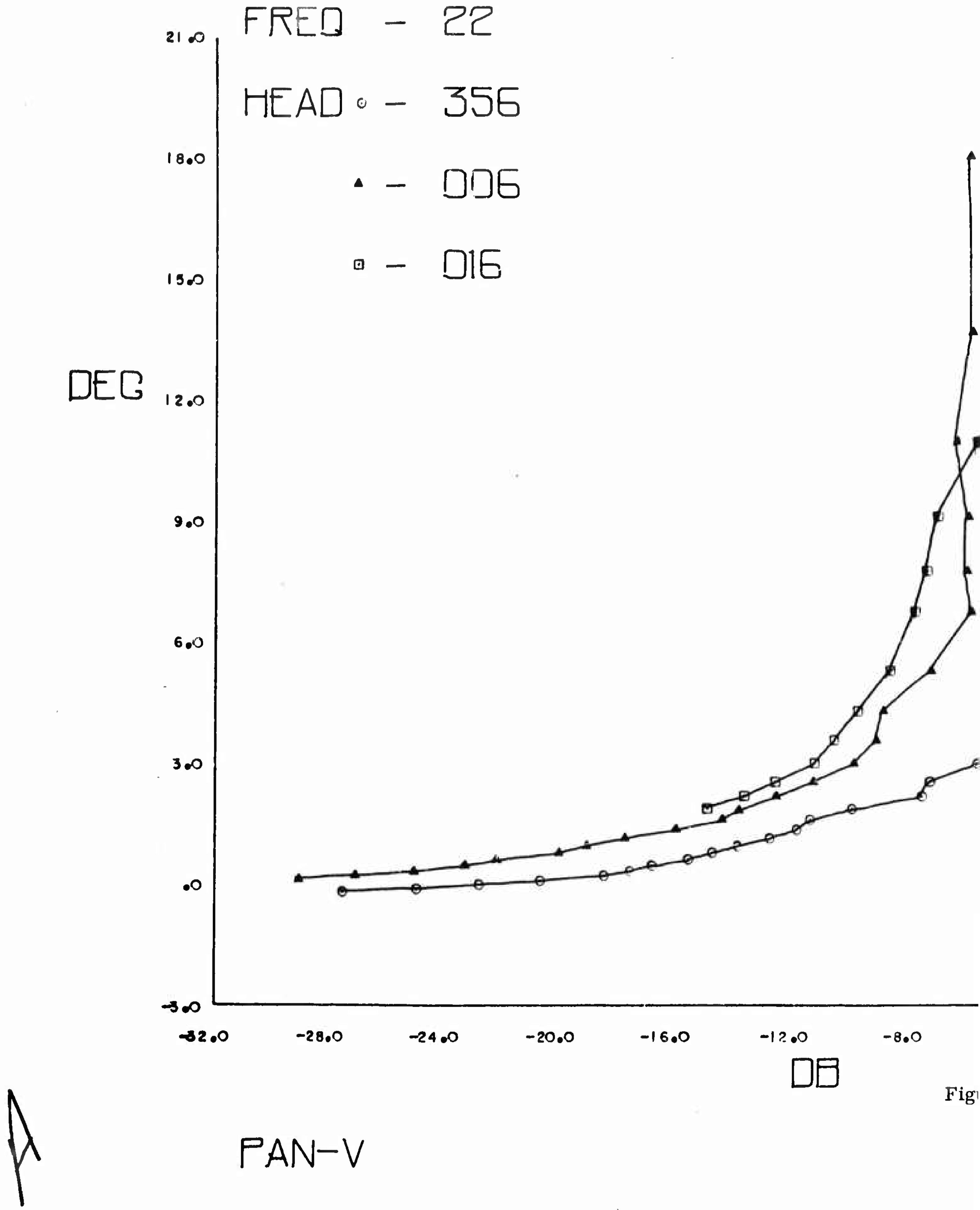


Figure 23. Panama Antenna
Patterns - 19 MHz

B


FREQ - 22
HEAD ⊙ - 356
▲ - 006
⊡ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-32.0
-28.0
-24.0
-20.0
-16.0
-12.0
-8.0
DB
PAN-V

Fig

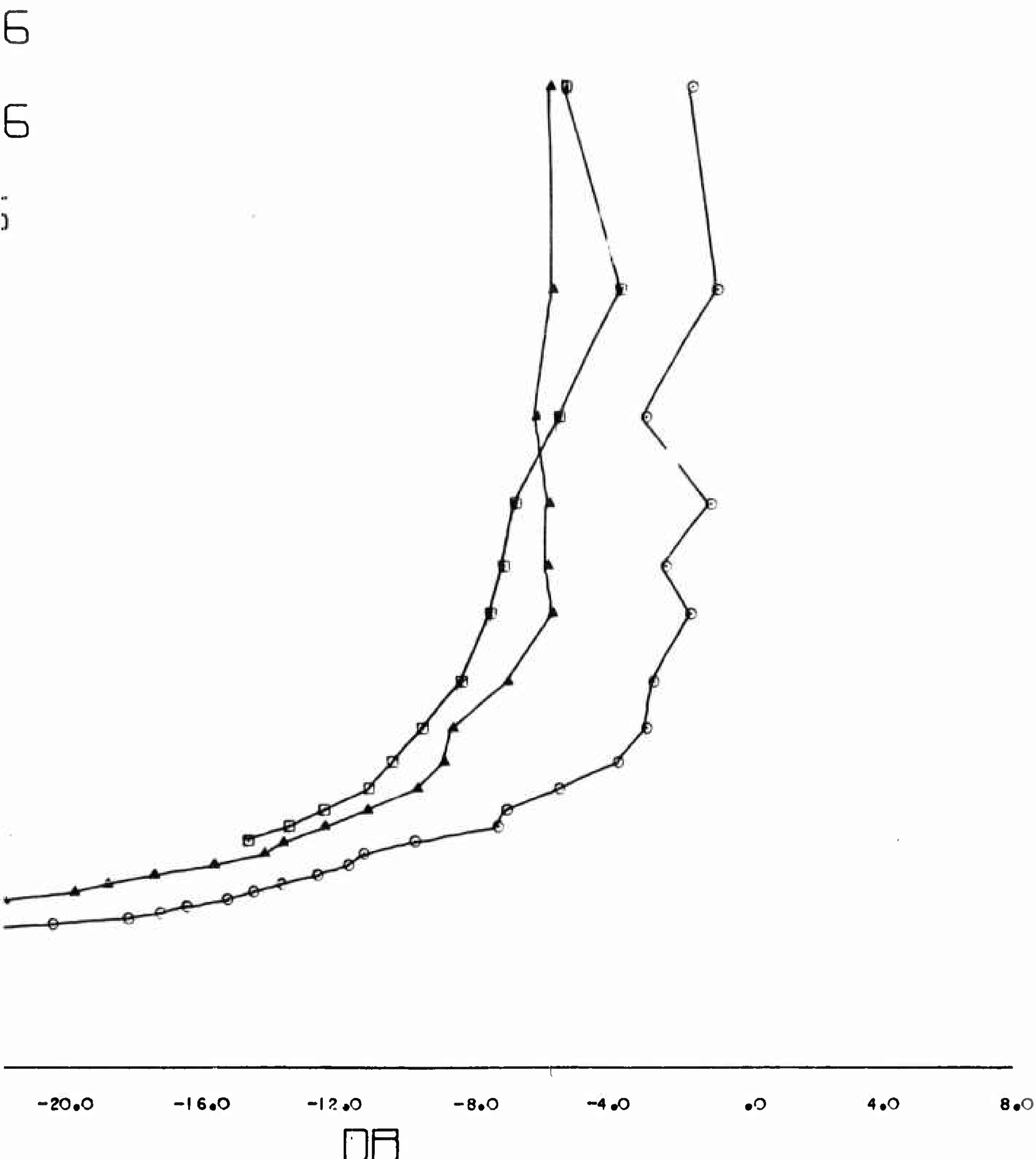
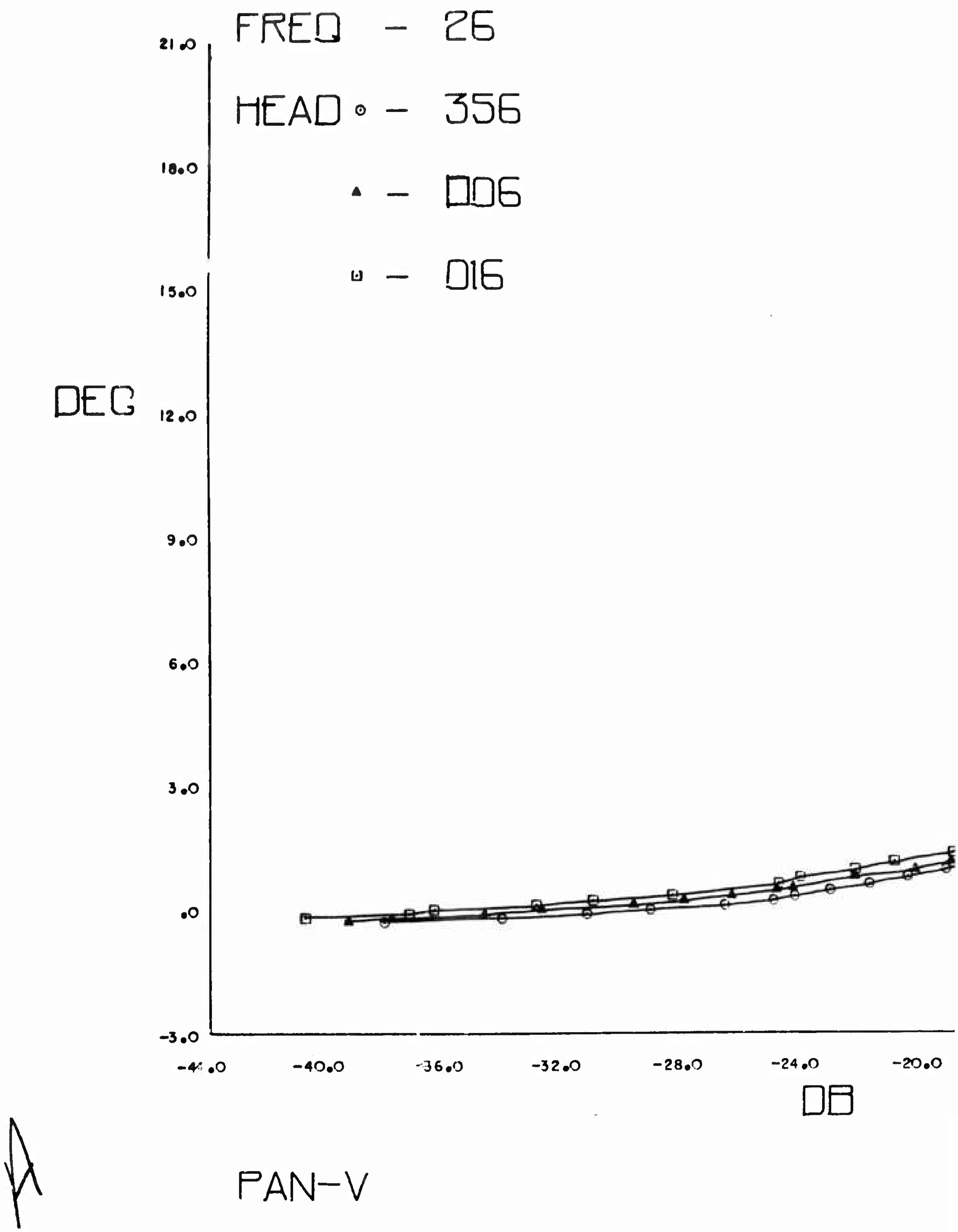


Figure 24. Panama Antenna
Patterns - 22 MHz

B


FREQ - 26
HEAD ○ - 356
▲ - 006
□ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
PAN-V

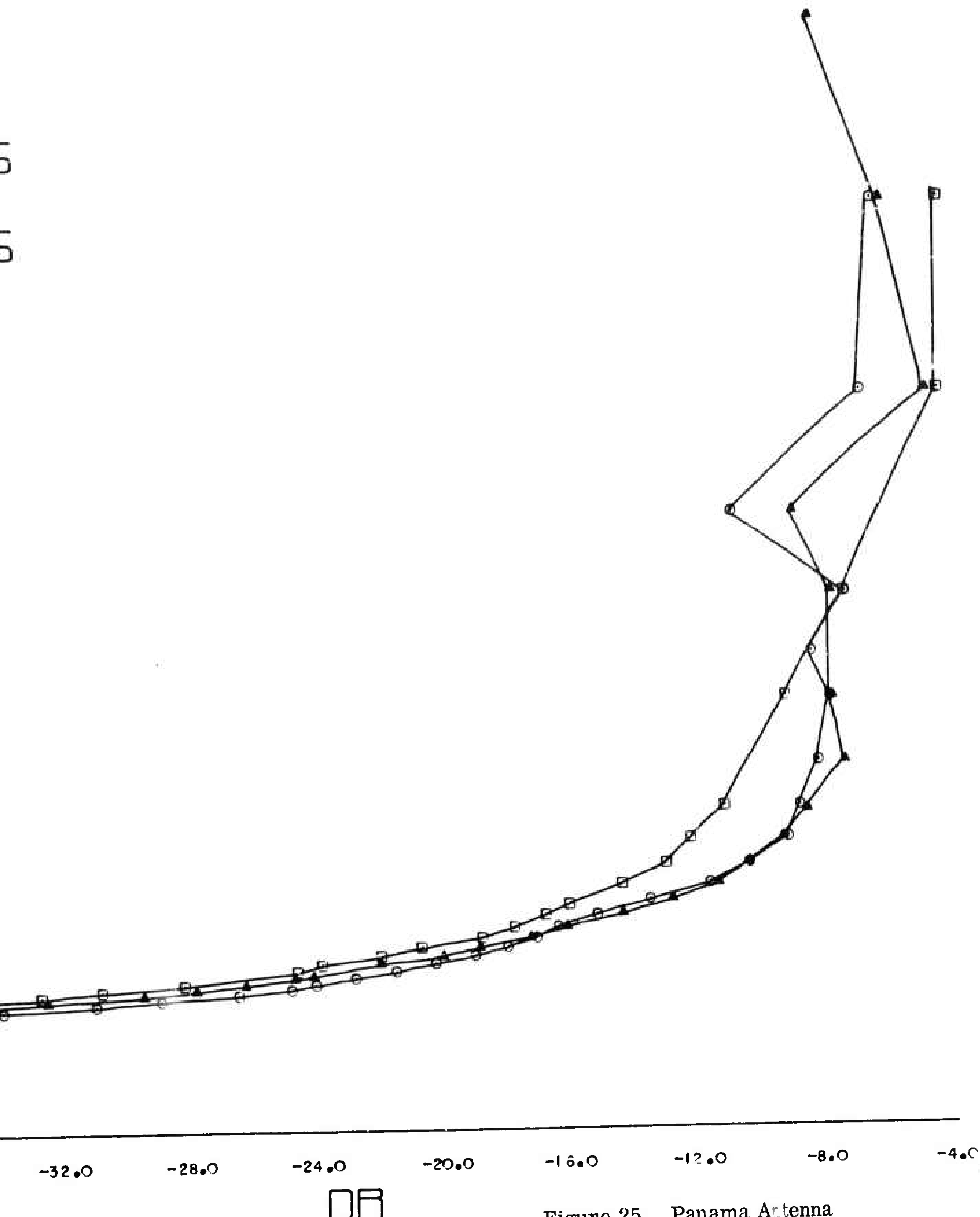
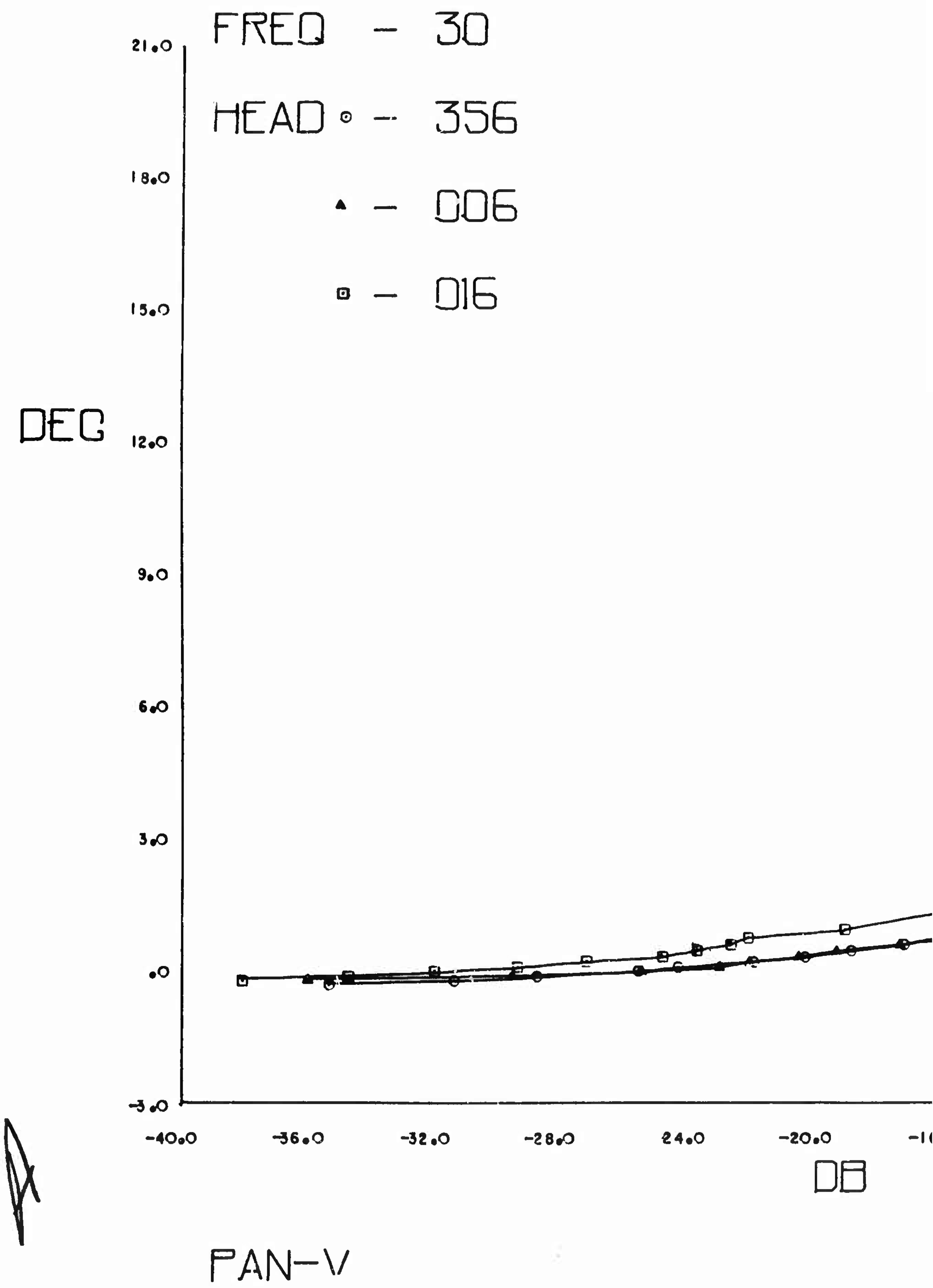


Figure 25. Panama Antenna
Patterns - 26 MHz

B


FREQ - 30
HEAD ⊙ - 356
▲ - 006
⊡ - 016
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
24.0
-20.0
DB
PAN-V

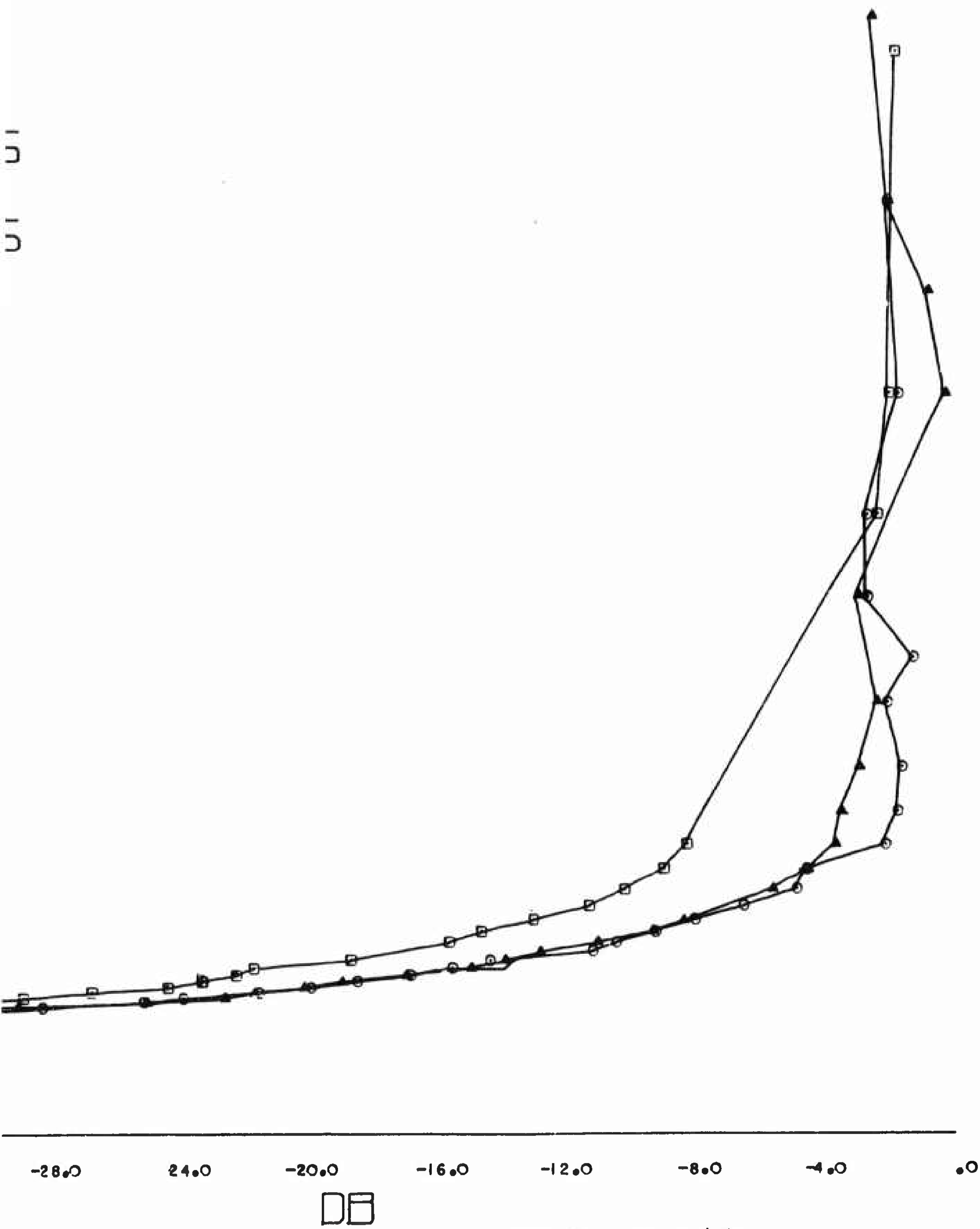


Figure 26. Panama Antenna Patterns - 30 MHz

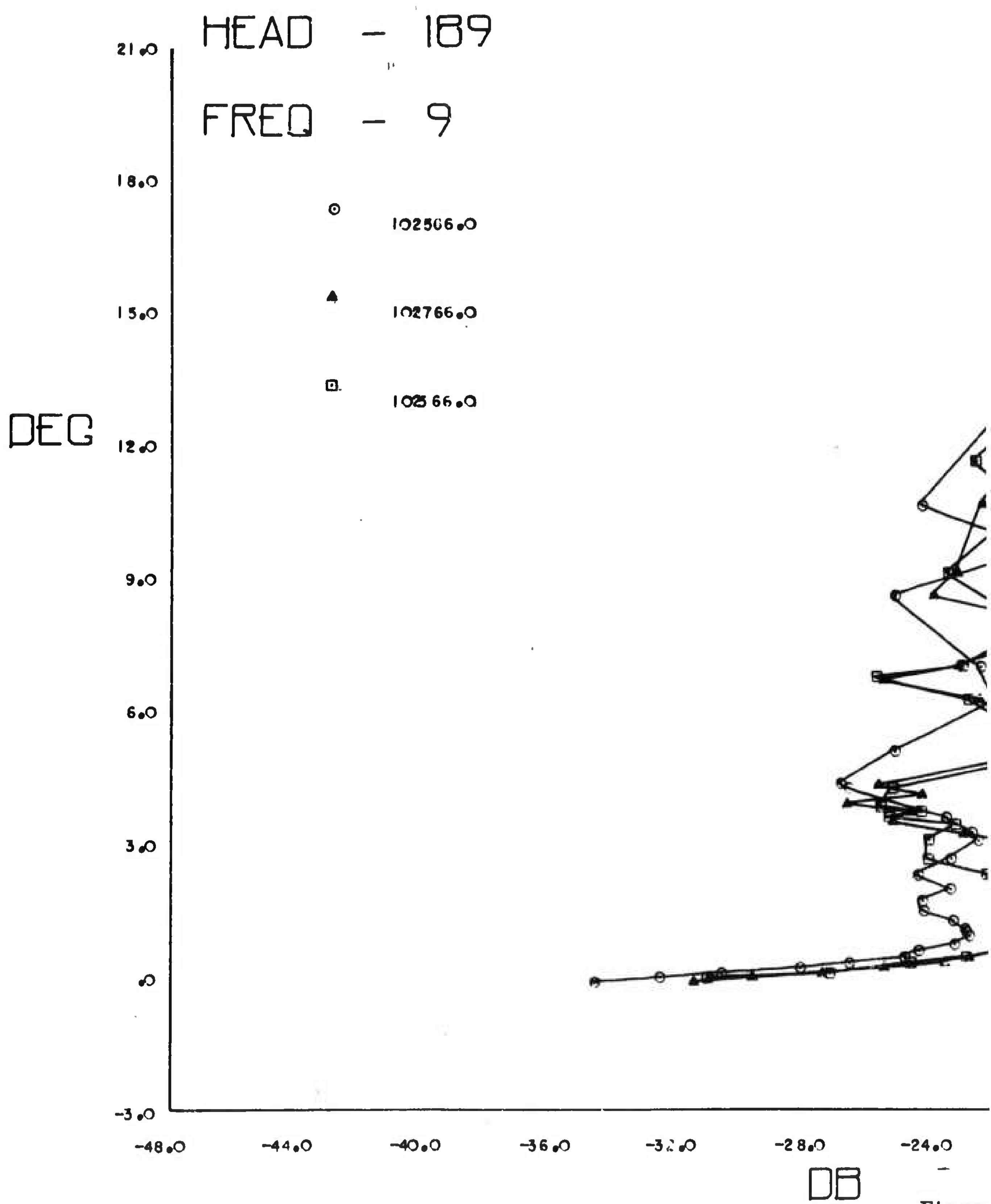
B

-10 degrees from boresight (356°) is consistently higher than the boresight (006°). There is a trend of increased pattern gain to the left of boresight. (This trend is borne out by the ±5° azimuths also.) Thus the direction of the main beam of the pattern differs by some 10 degrees from the direction in which the antenna is pointing. The main reason for this is the proximity of sea water to the left side of the antenna.

The next step was the reduction of these patterns to a form that can be used in the mode loss computer program. There are a number of methods that could be employed to do this. At first, consideration was given to fitting these curves with polynomial functions of the elevation angles. If the data could be matched with a set of low order polynomials it would mean a savings in computer time and space. This method turned out, however, to be less efficient than a simple table look-up. This latter method consists of (1) setting up a set of tables of gain versus elevation angle, (2) using this table to interpolate to the elevation angle of interest on the two frequencies adjacent to the frequency of interest, and (3) interpolating between the two values thus obtained. Therefore the gain can be calculated at any elevation angle and frequency in the range of the data.

Sample results of the measurements of the Thule antenna are shown in Figures 27, 28, and 29. These results are for typical low, mid, and high frequencies. These results are completely at variance with the results obtained on the Panama antenna. The Thule antenna siting is the cause of this dissimilarity. This antenna is located about one-half mile above sea level (see Figure 3). The lobes in this pattern are caused by (1) interference between the antenna and its image, and (2) diffraction around the sharp ridges in front of the antenna. A discussion of this problem may be found in Reference 1. Figures 30 through 37 are the average patterns of the Thule antenna on boresight. The patterns at the other azimuths are similar. Looking at the patterns at different frequencies, it can be seen that the peaks and nulls occur at different angles in each case. Because of this, we cannot directly interpolate between frequencies. Instead, a method was derived which fits the data in terms of the number of the null.[10] Using this method an interpolation scheme was established which takes into account the location of these peaks and nulls.

Typical data curves for the Iceland antenna patterns are shown in Figure 38 and their average is in Figure 39. Although the flight plan called for the same number runs as at other sites, less valid data runs were obtained. Several data runs could not be used because of instabilities of the voltage levels in the recorder. The average curves for the Iceland antenna are shown in Figures 40 through 47. The curves are shown for boresight (260°) and ±10° off boresight. There is a tendency for the +10° bearing (270°) to have a higher gain than the boresight and for both of these to be higher than the -10° (250°) bearing. Since the gains for the 260° and 270° azimuths are close together it appears that the peak of the beam is offset less than 10 degrees to the north from the boresight of the antenna. As in the case of the Panama antenna, the ocean is closer on the side to which the beam is offset.



Figure

THU-V

A

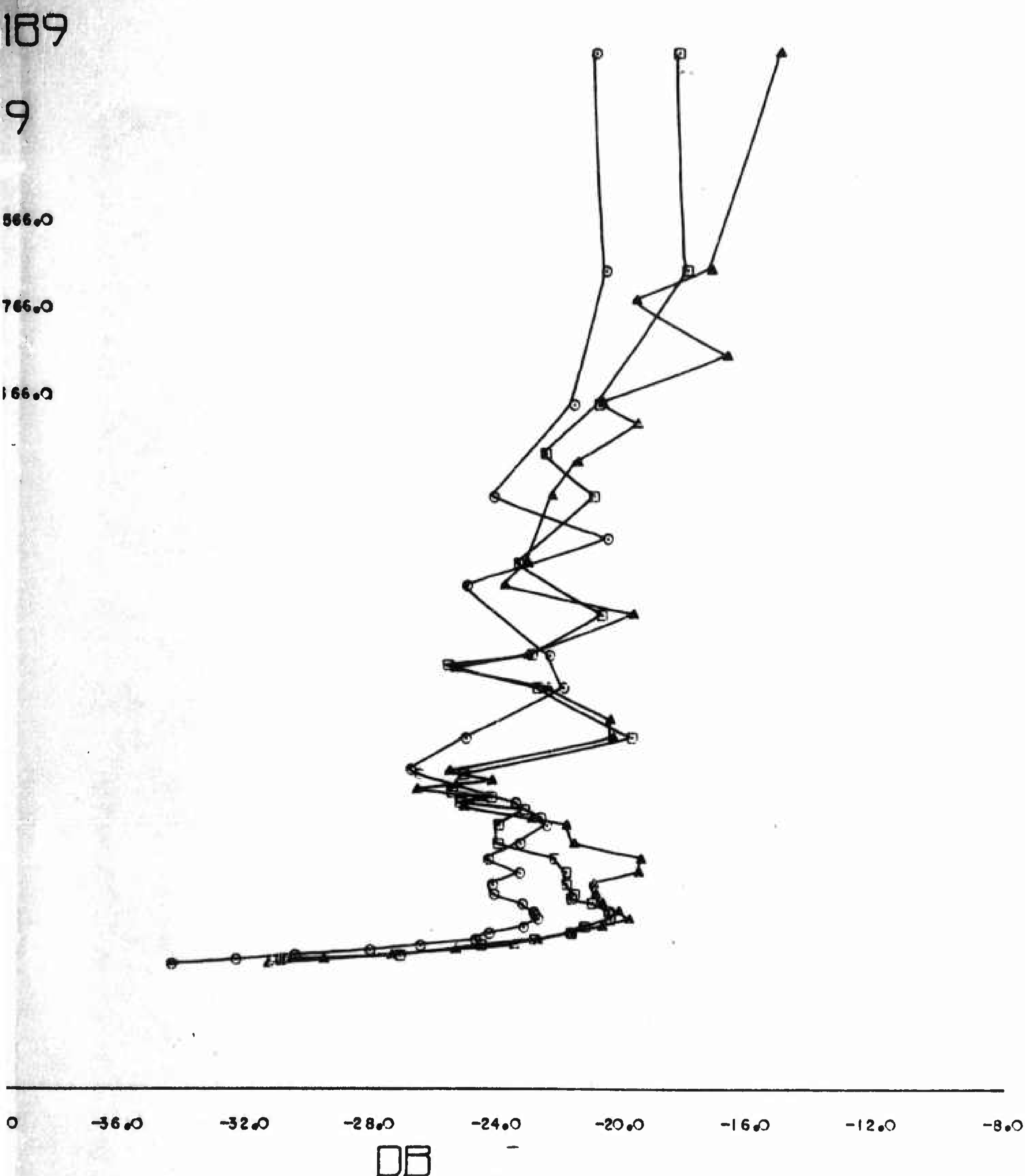
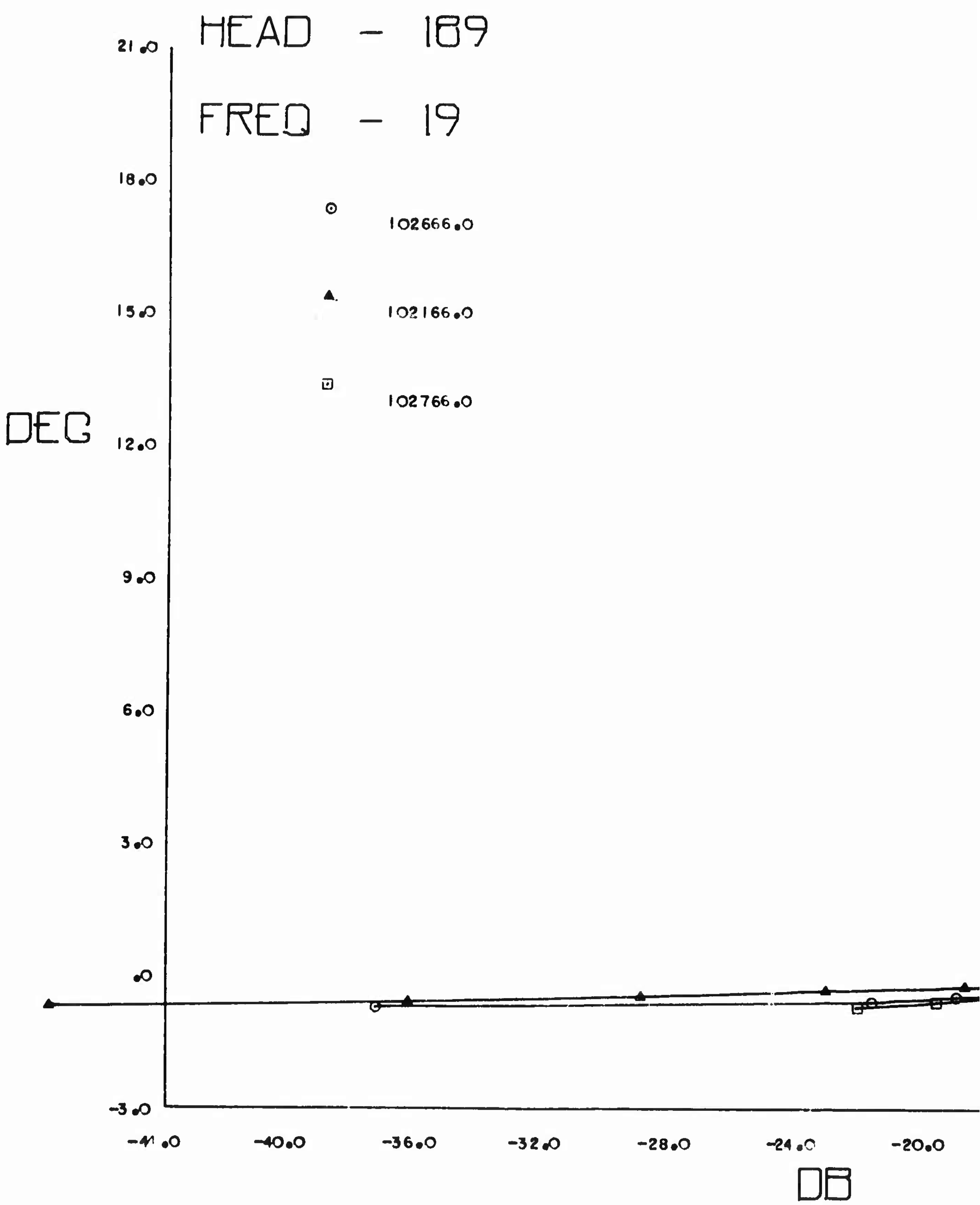


Figure 27. Program TAPPLT - Plot Output (Thule - 9 MHz)

B


HEAD - 189
FREQ - 19
102666.0
102166.0
102766.0
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB

A

THU-V

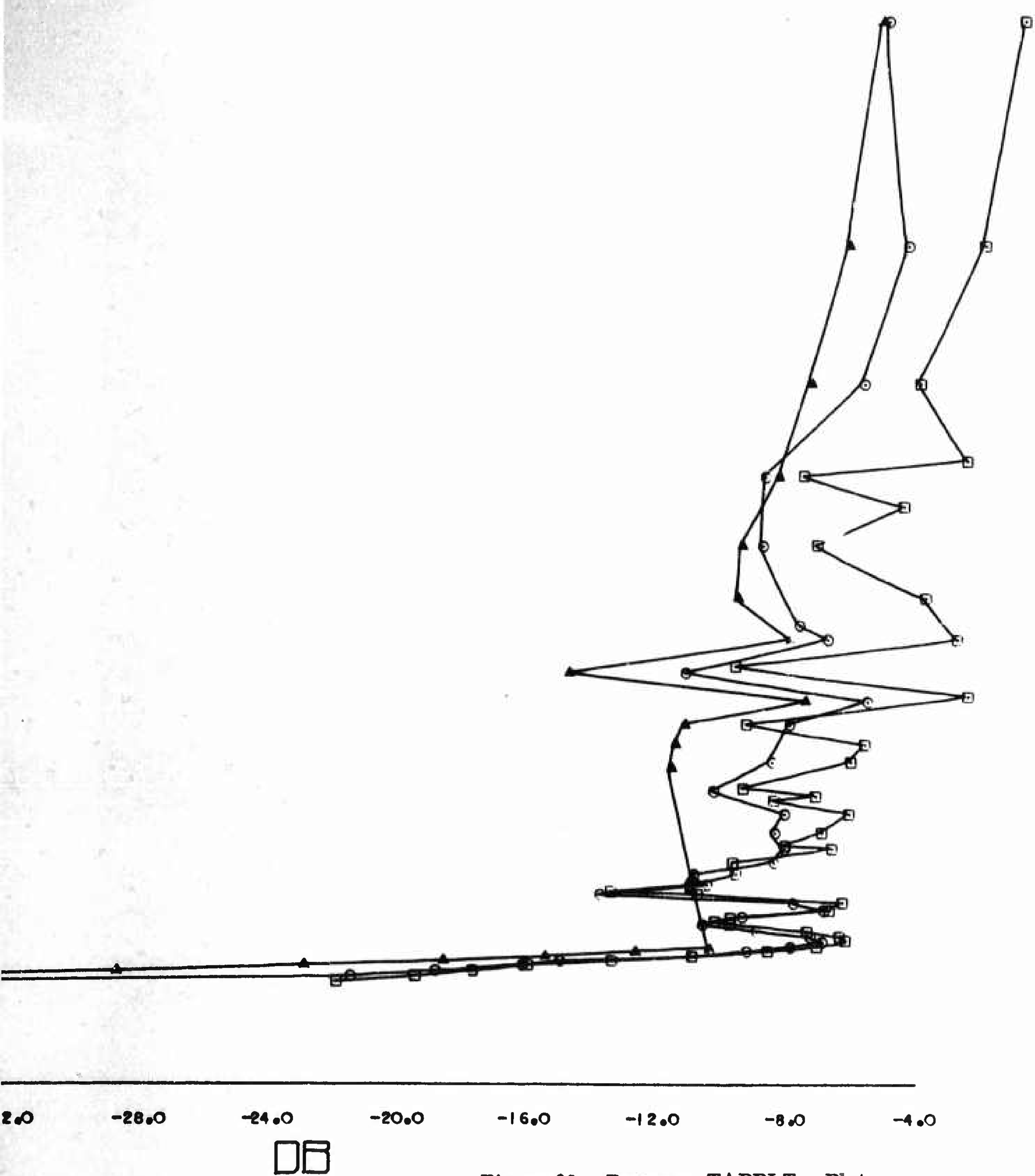
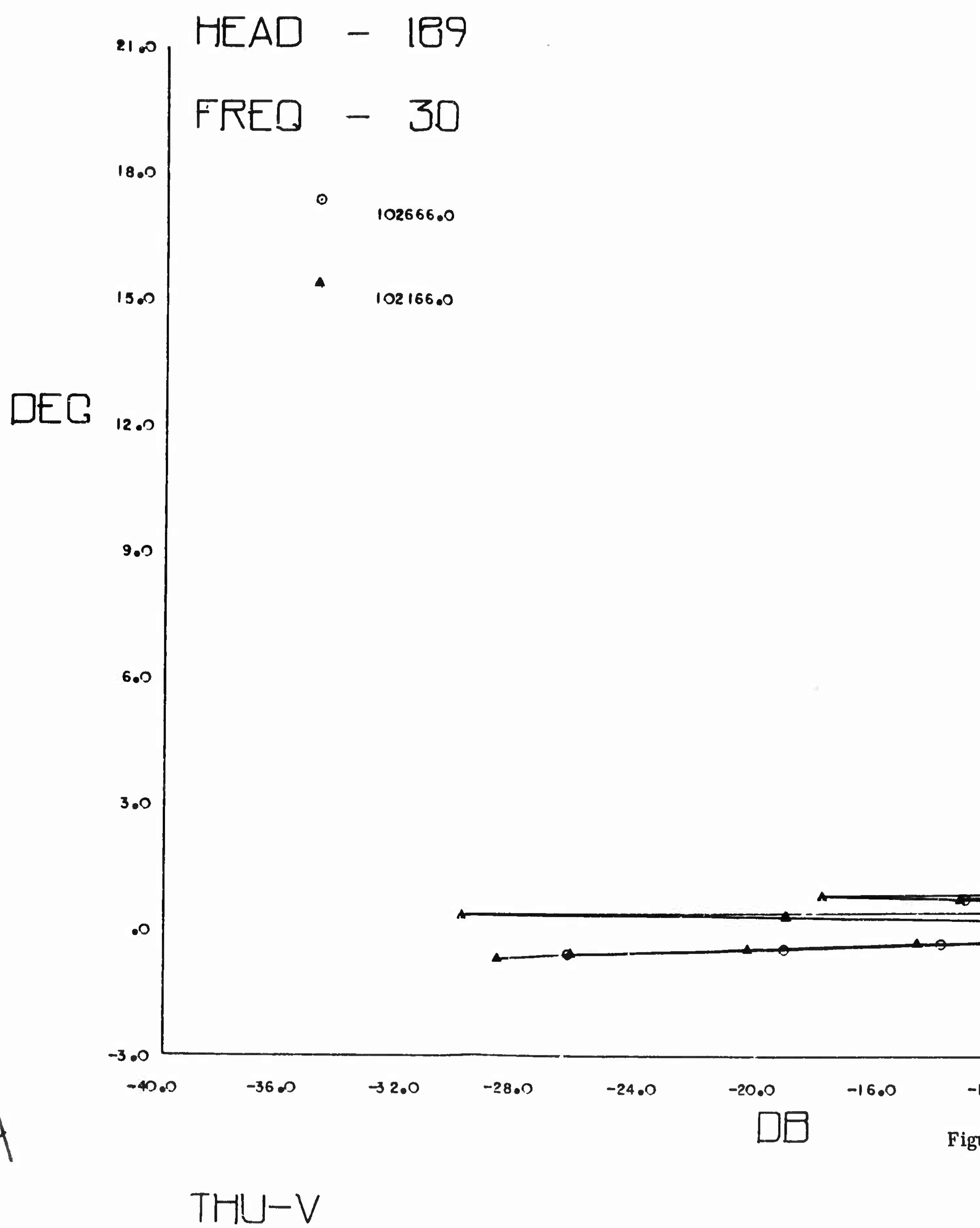


Figure 28. Program TAPPLT - Plot Output (Thule - 19 MHz)

B


HEAD - 189
FREQ - 30
102666.0
102166.0
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
DB
THU-V

Figu

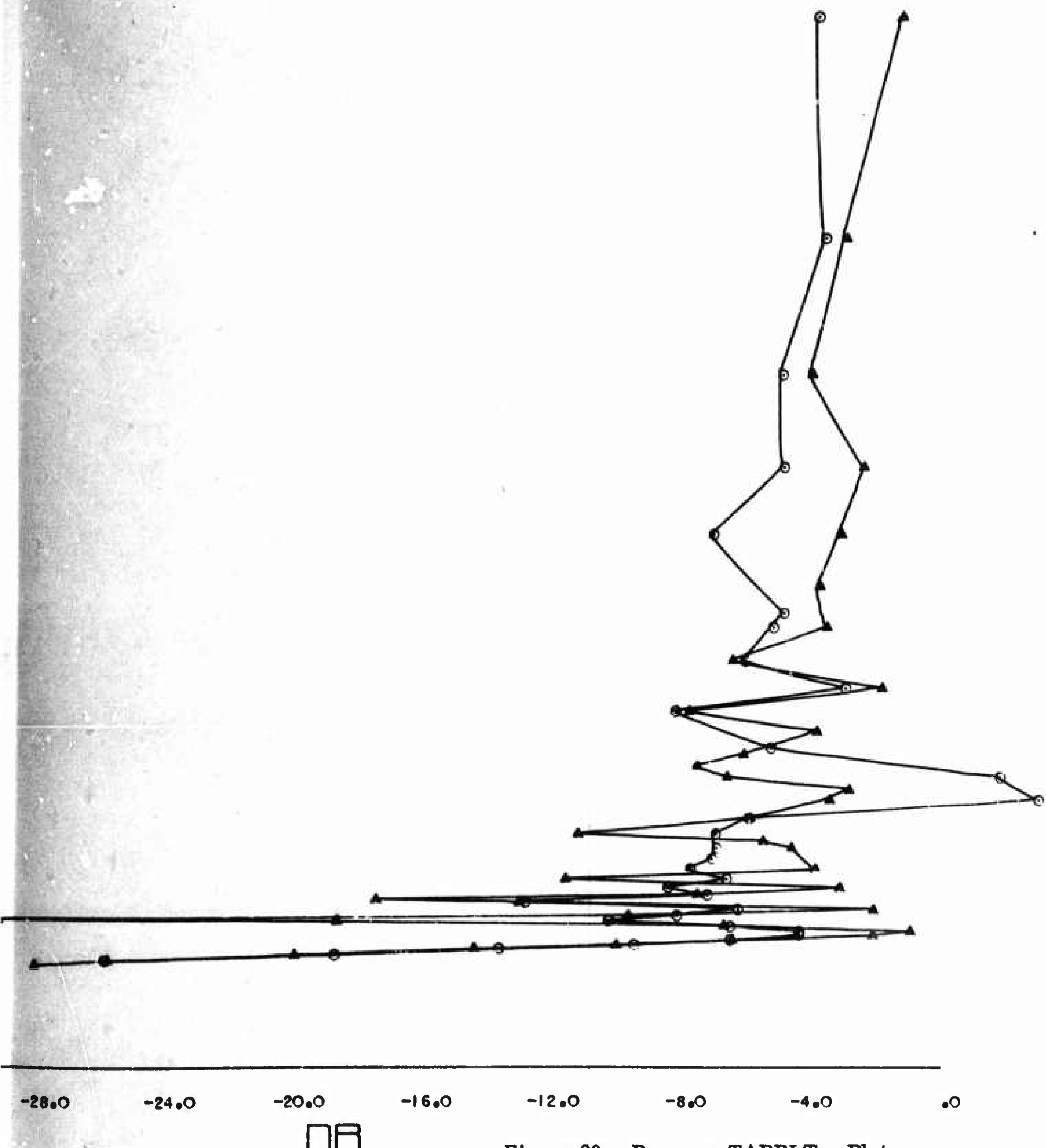


Figure 29. Program TAPPLT - Plot Output (Thule - 30 MHz)

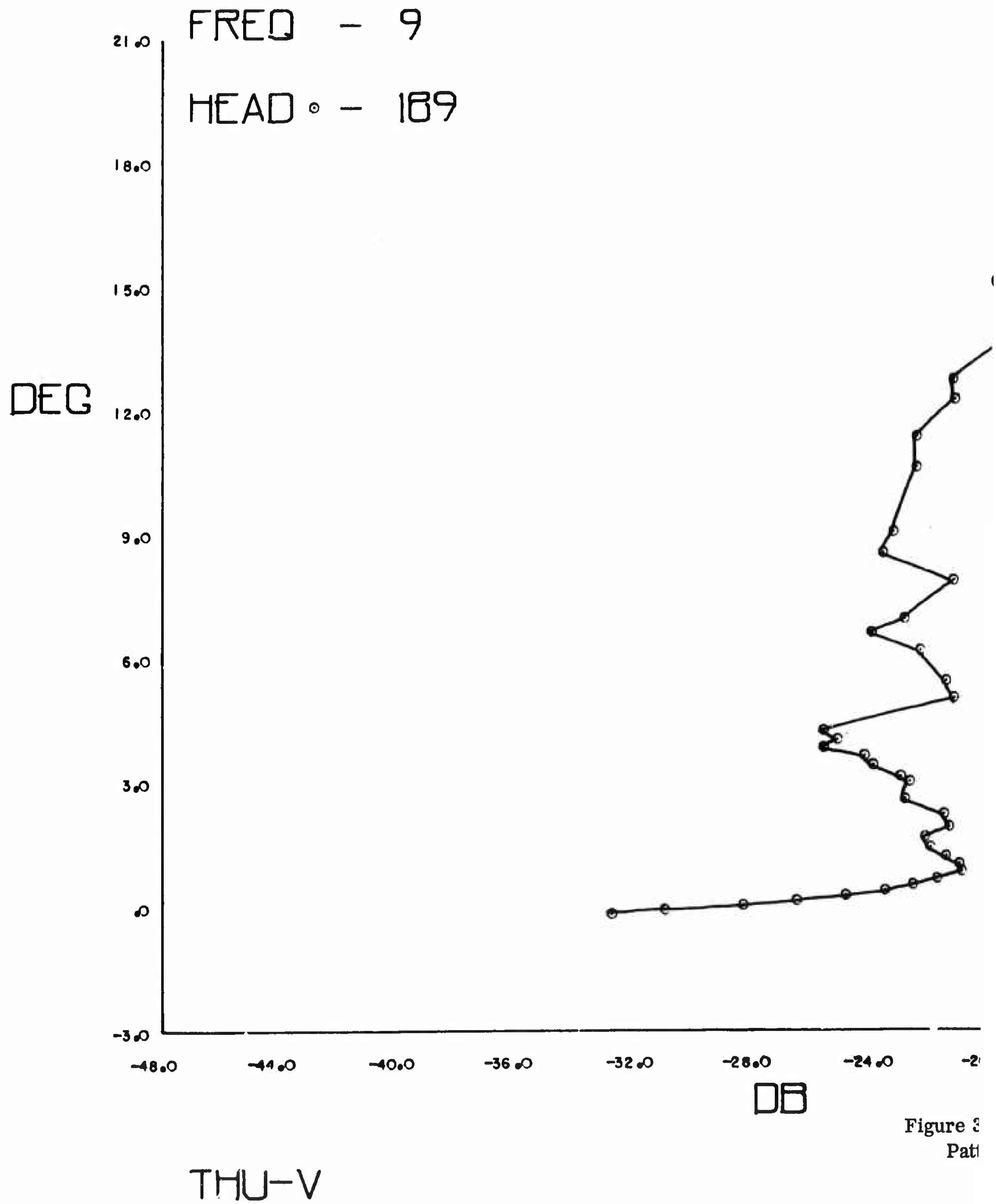


Figure 3
Patt

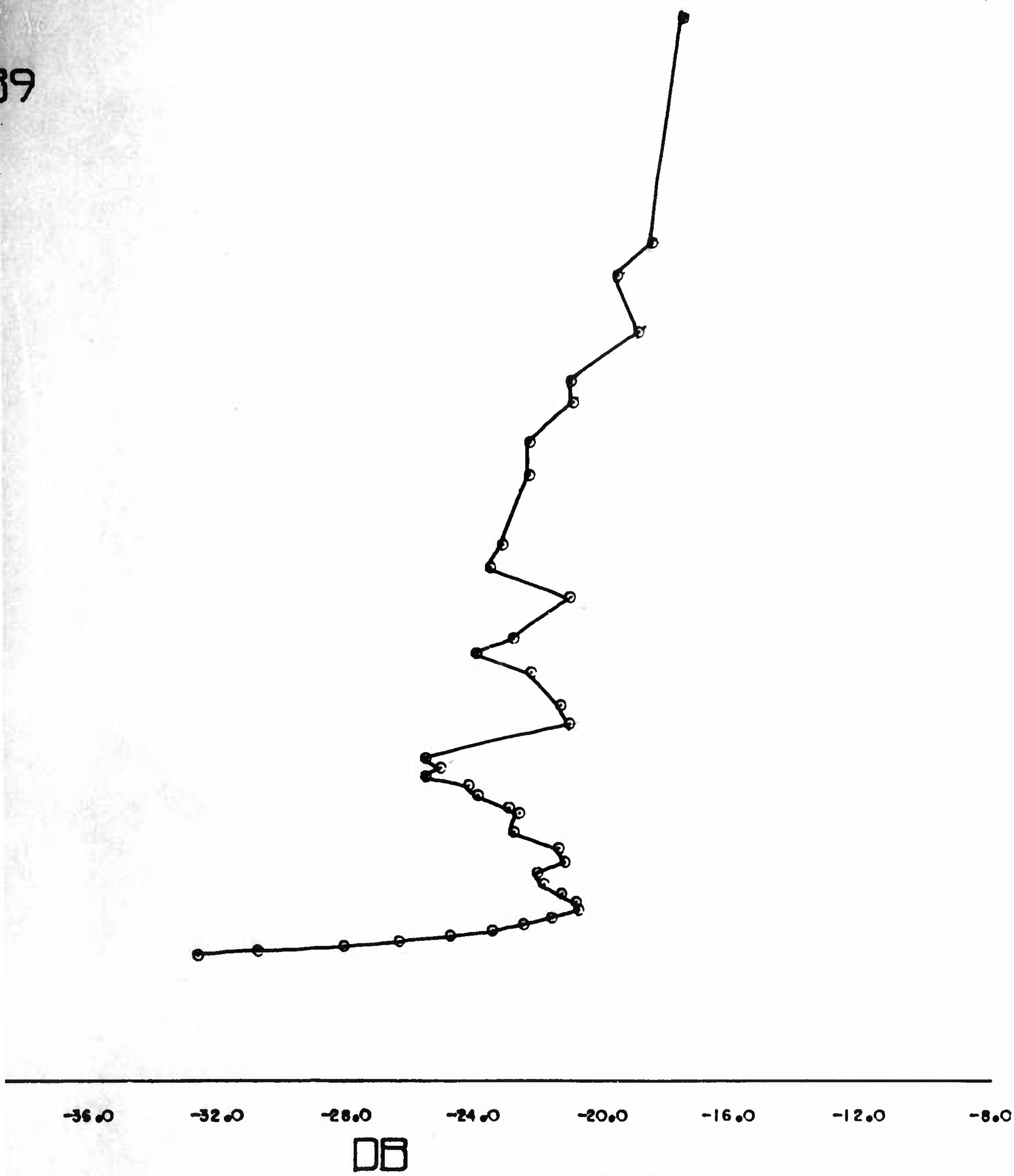


Figure 30. Thule Antenna
Patterns - 9 MHz

B

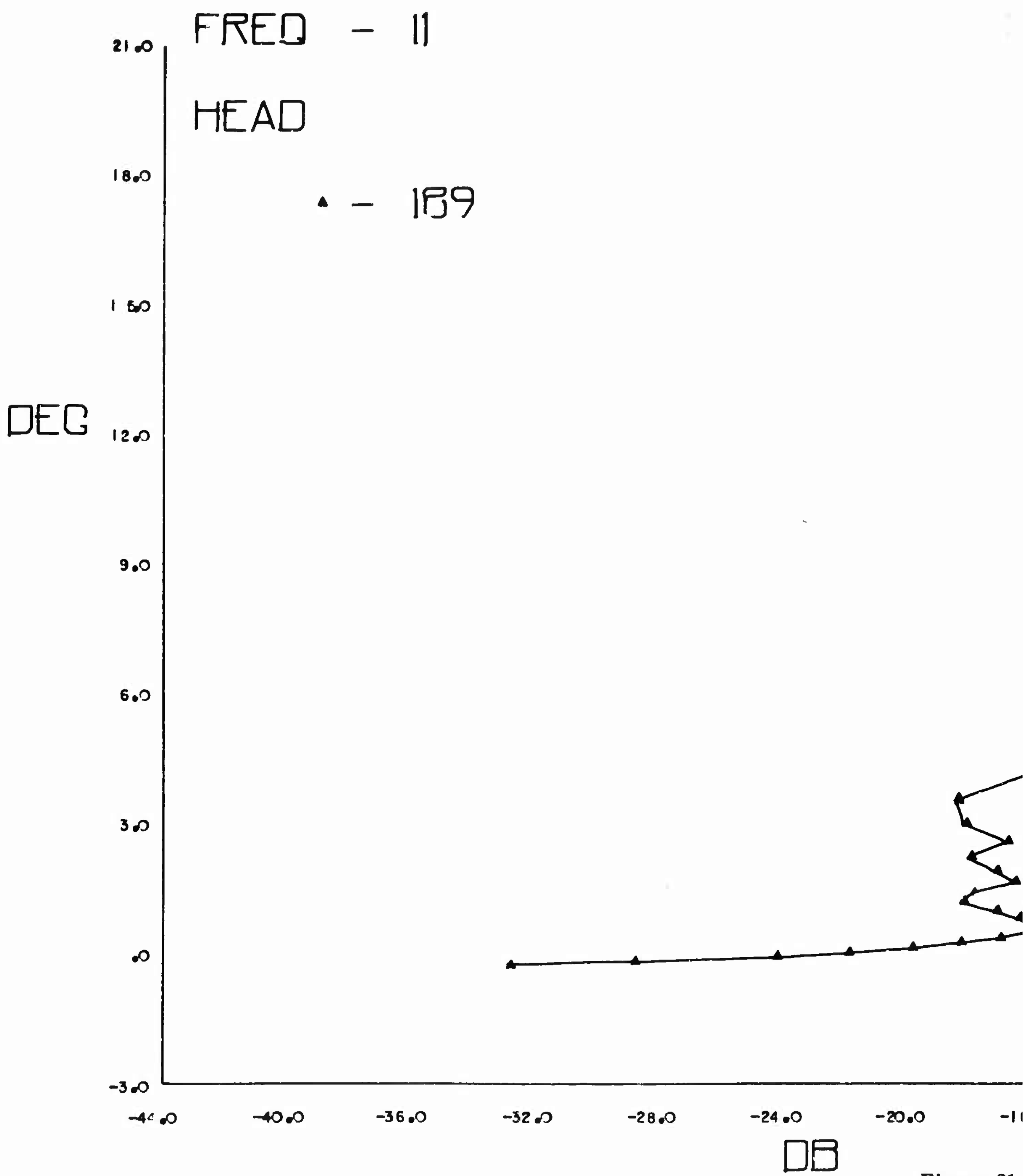


Figure 31.
Patte

A

THU-V

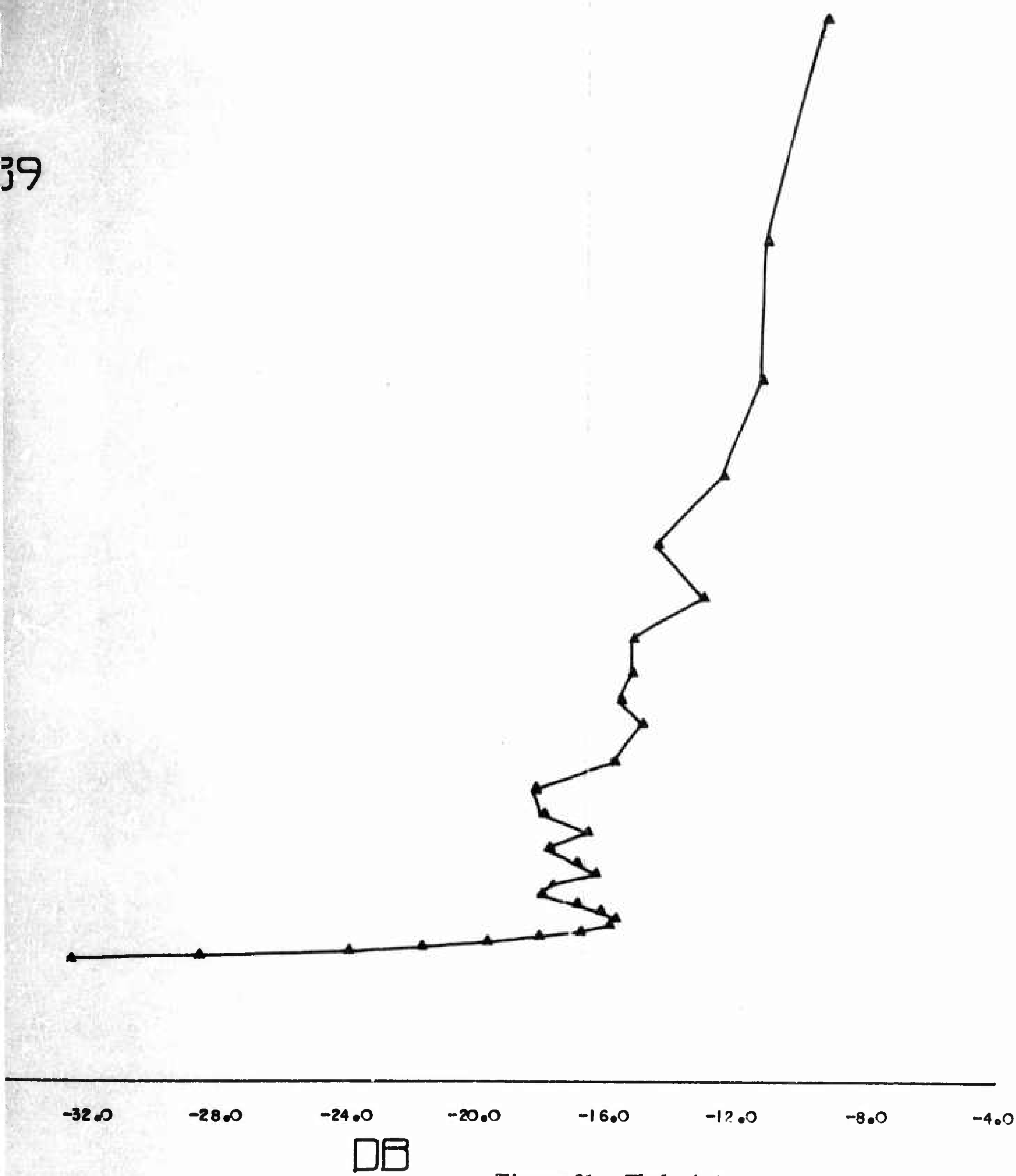
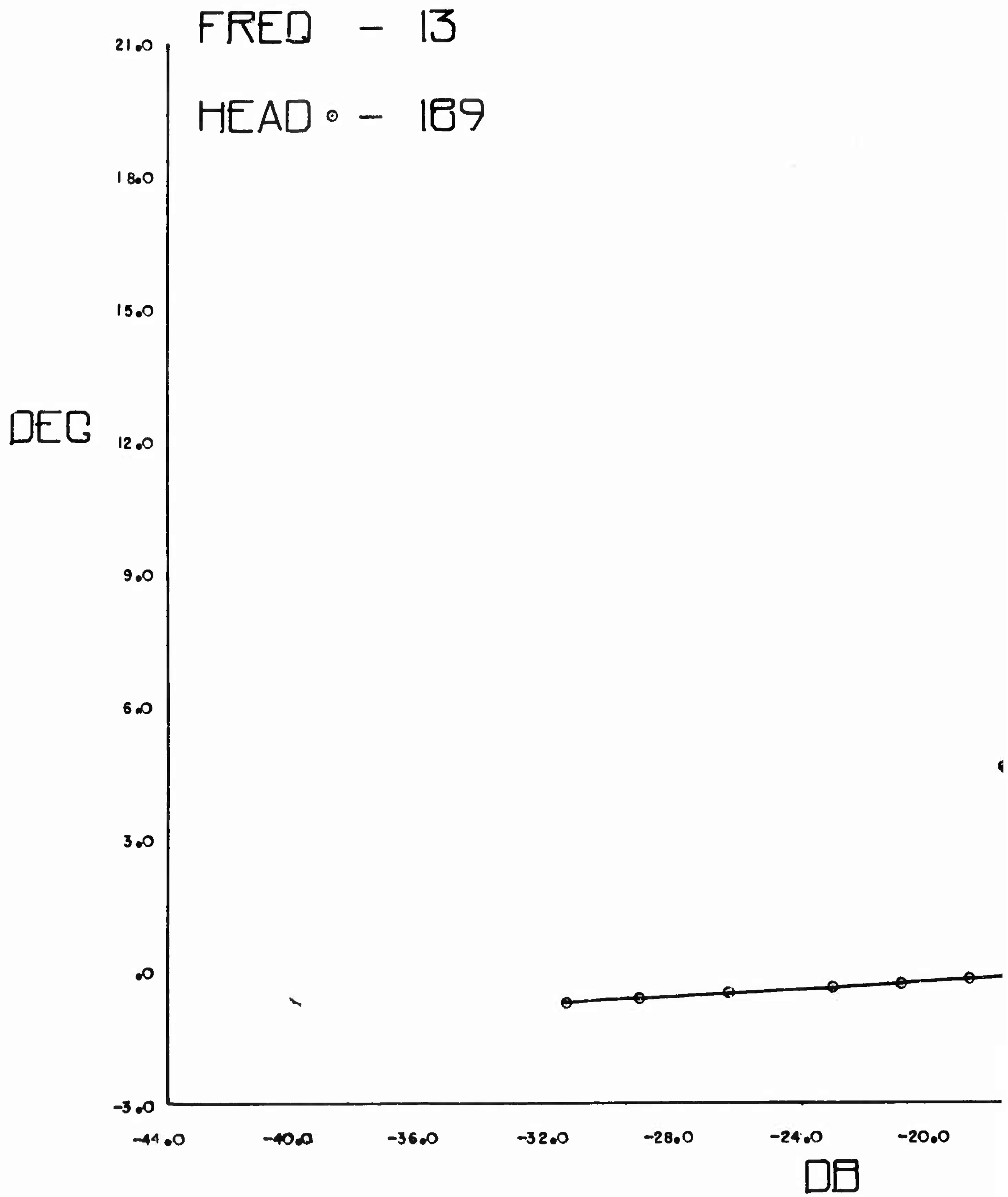


Figure 31. Thule Antenna
Patterns - 11 MHz

B


FREQ - 13
HEAD ° - 189
21.0
18.0
15.0
DEG
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB

A

THU-V

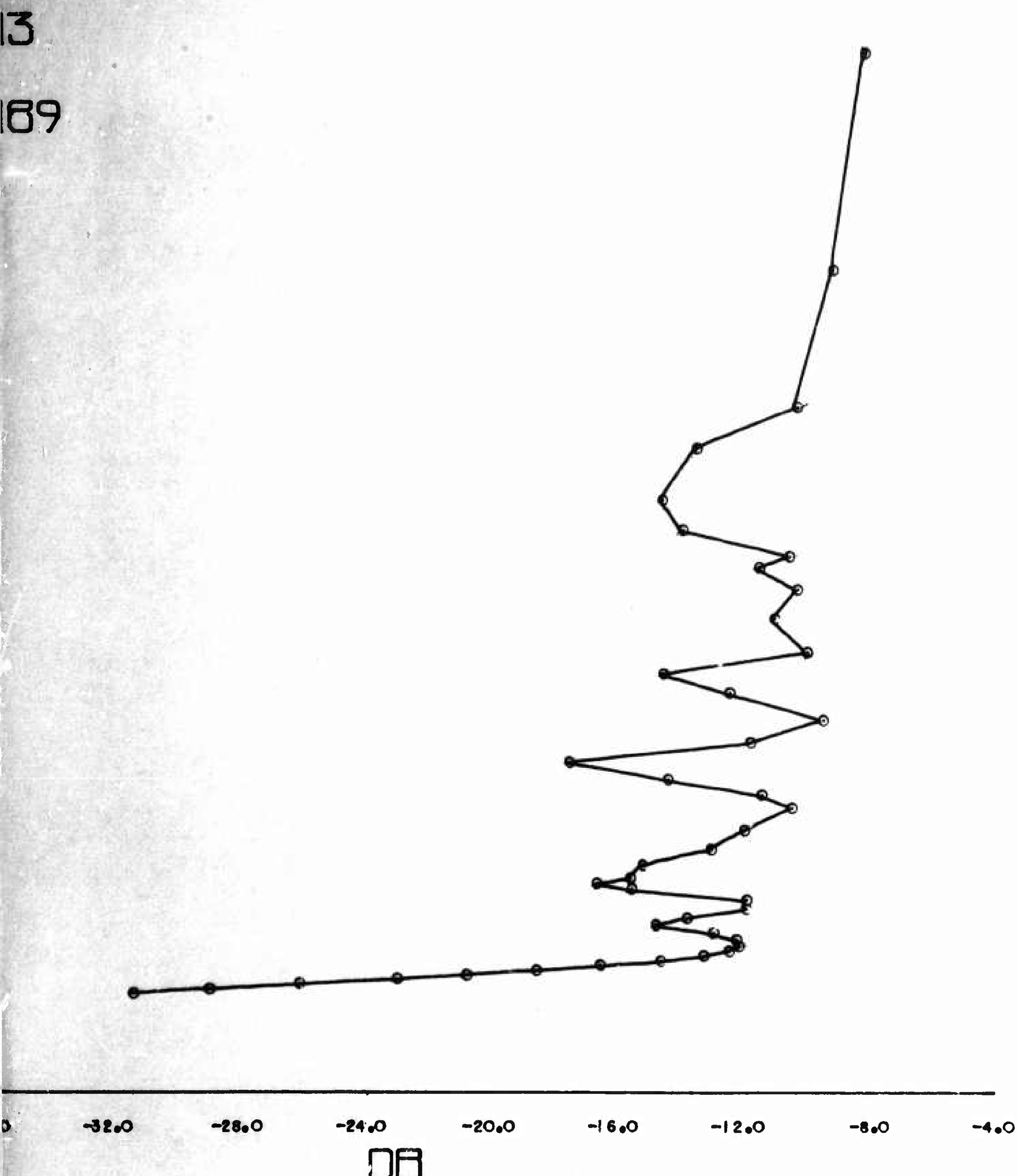
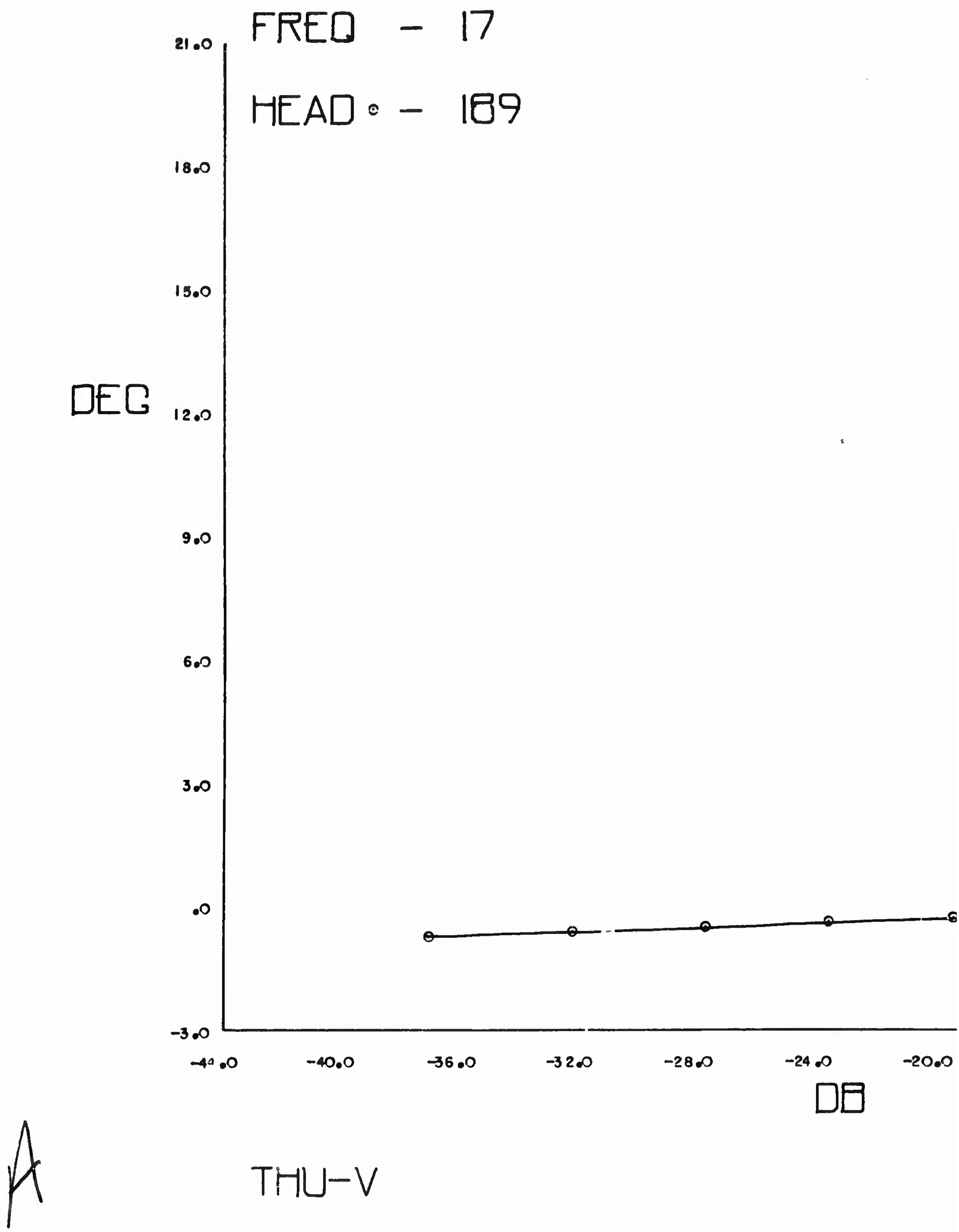


Figure 32. Thule Antenna Patterns - 13 MHz

B


FREQ - 17
HEAD ° - 189
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-44.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
DB
A
THU-V

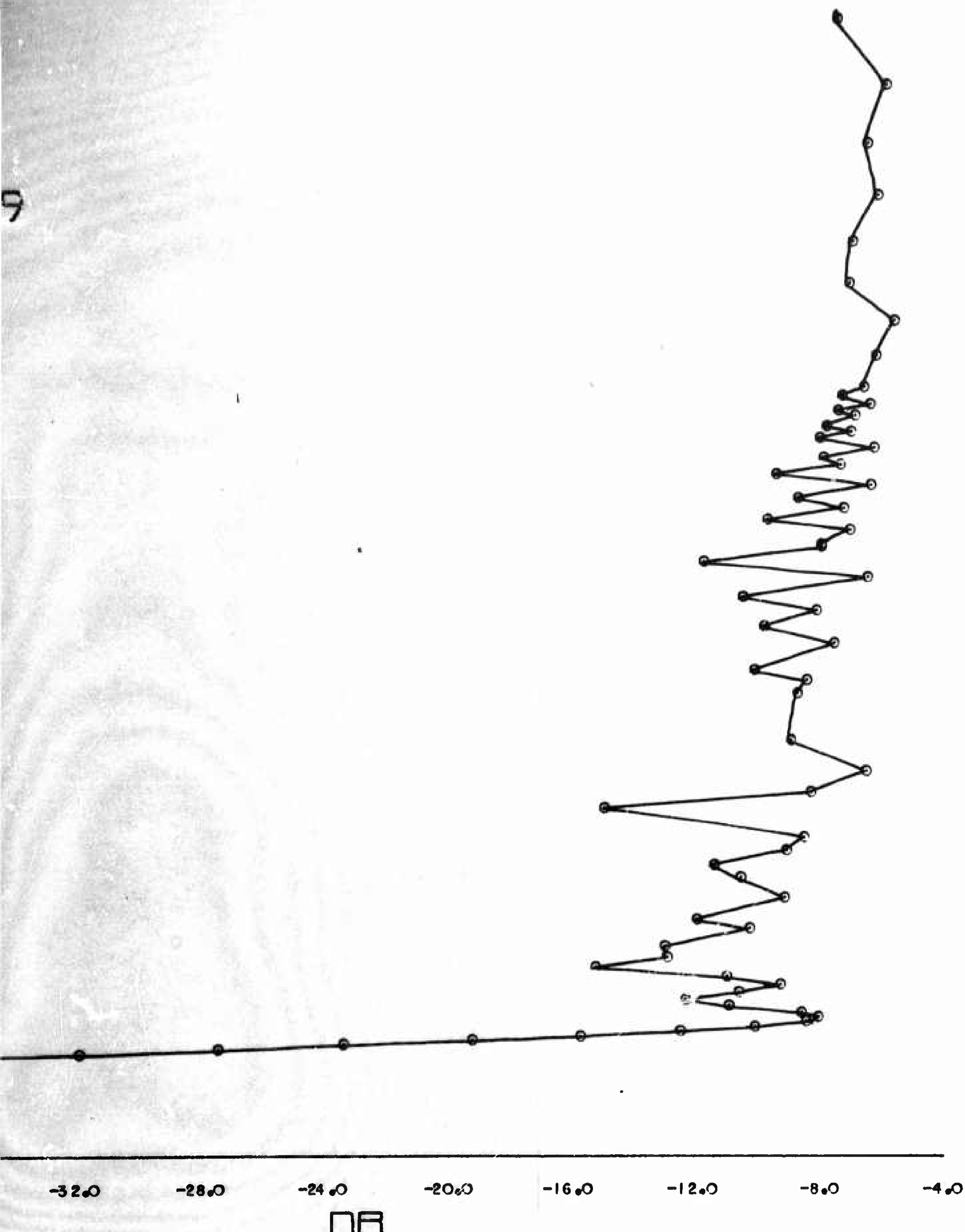
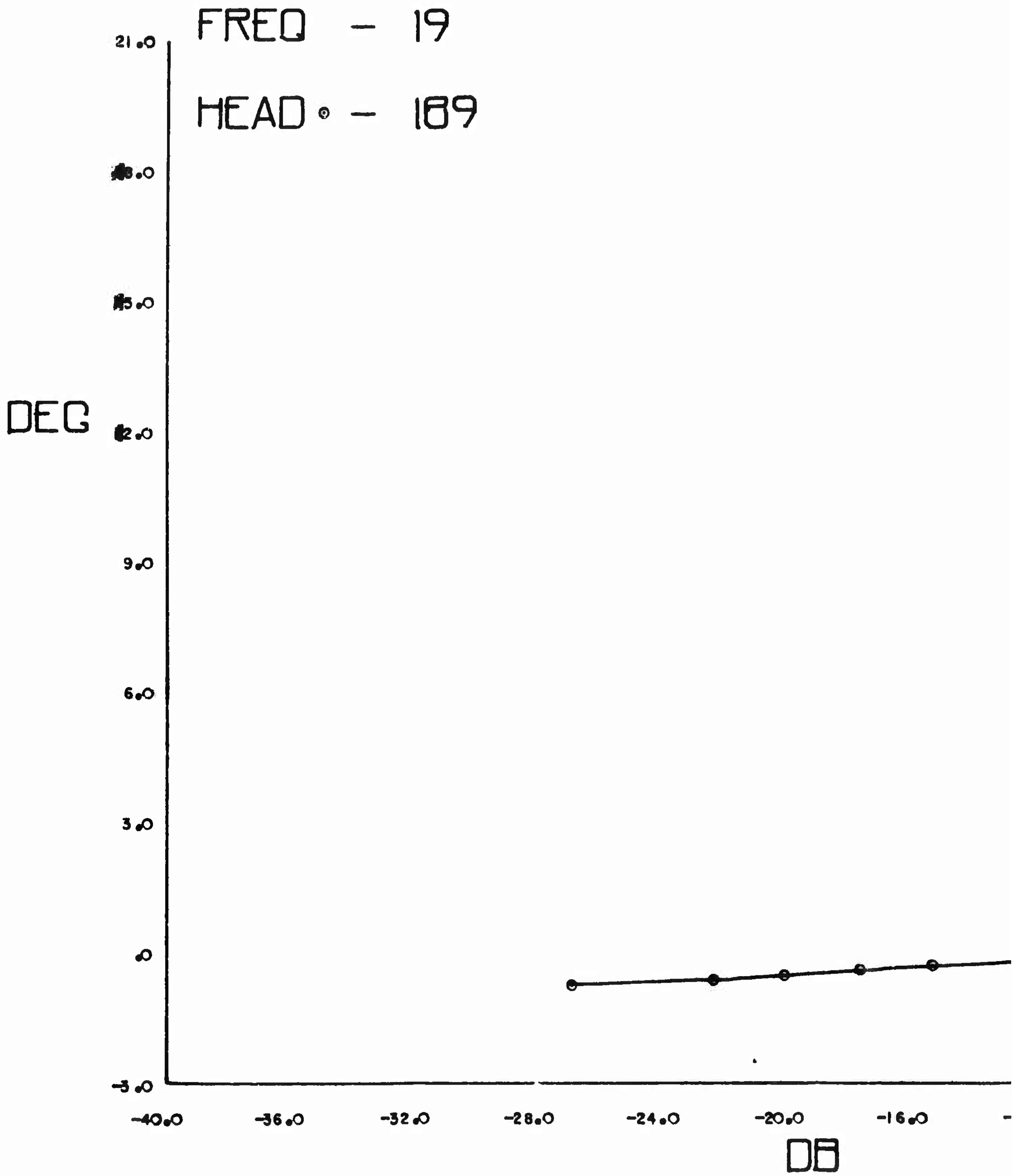


Figure 33. Thule Antenna Patterns - 17 MHz


FREQ - 19
HEAD° - 189
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
DB

THU-V

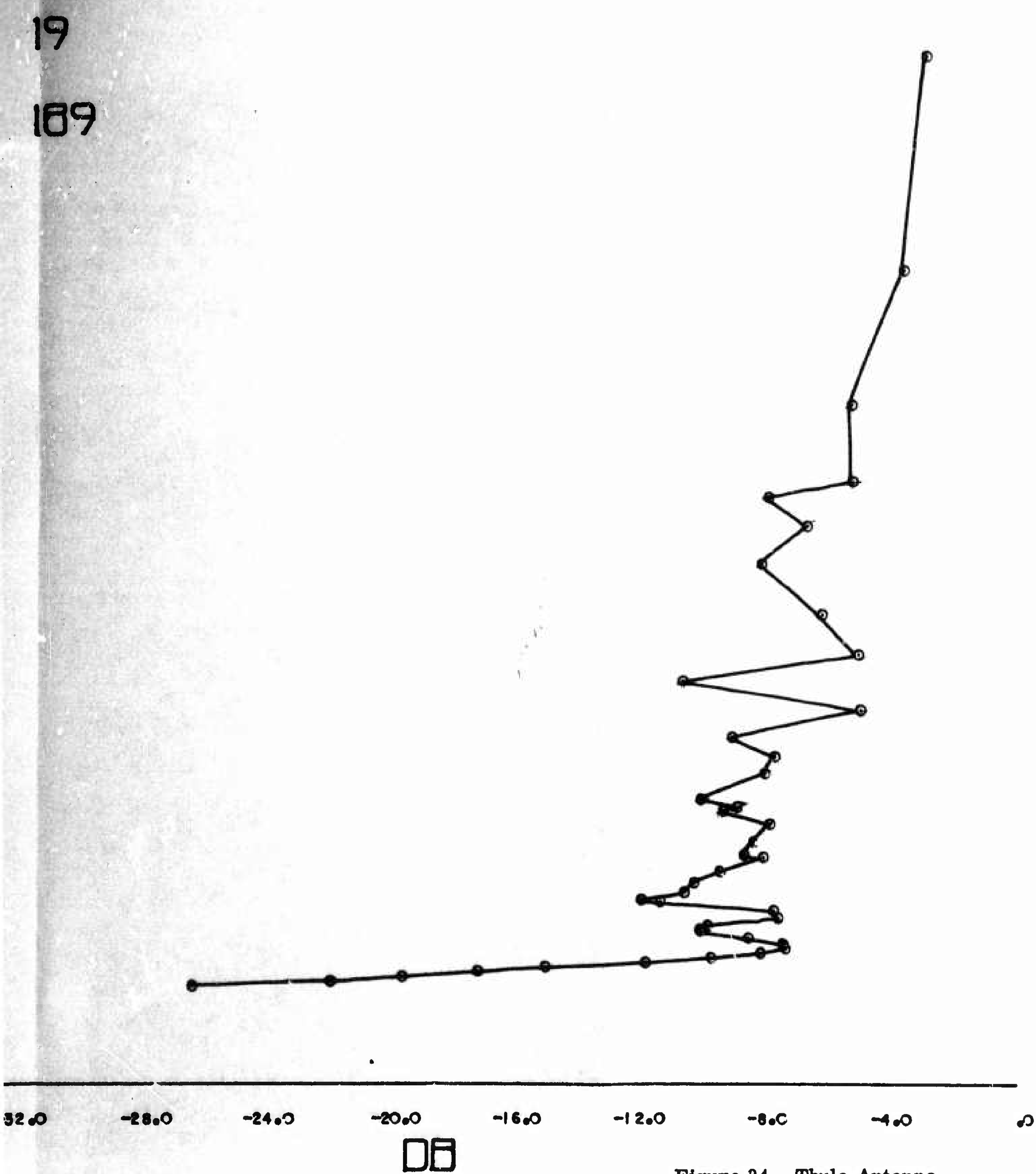
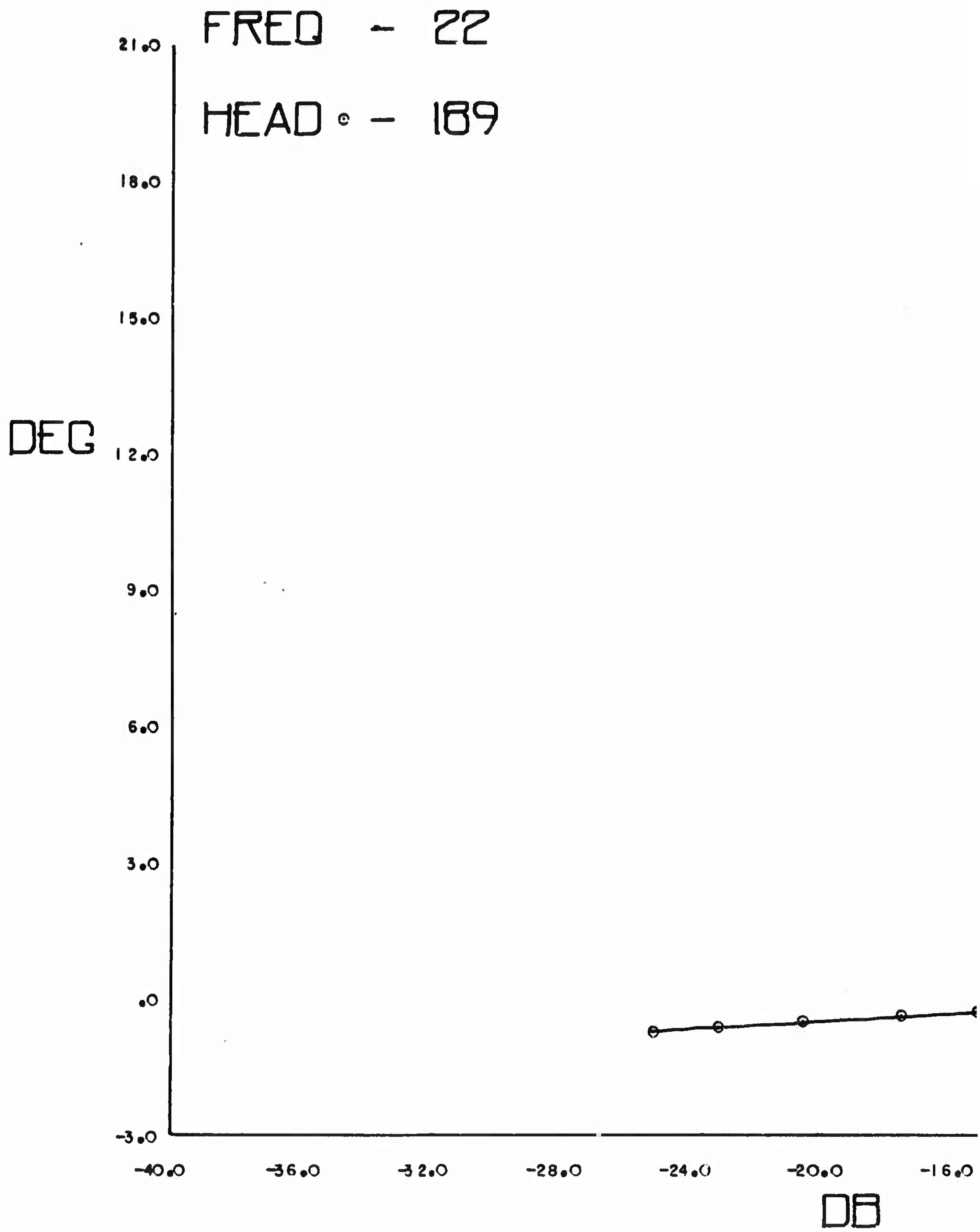


Figure 34. Thule Antenna Patterns - 19 MHz



FREQ - 22
HEAD° - 189
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
DB

A

THU-V

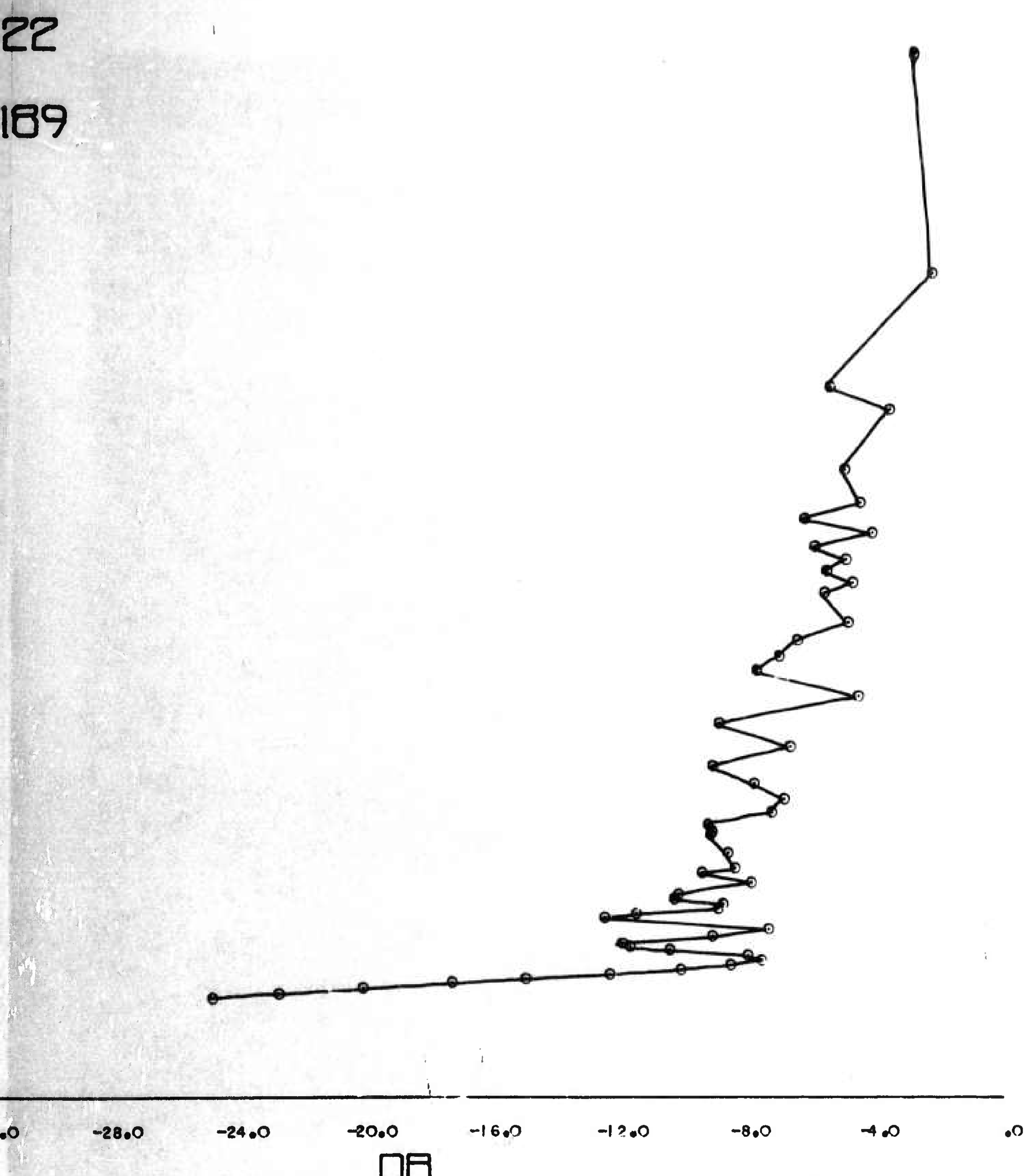
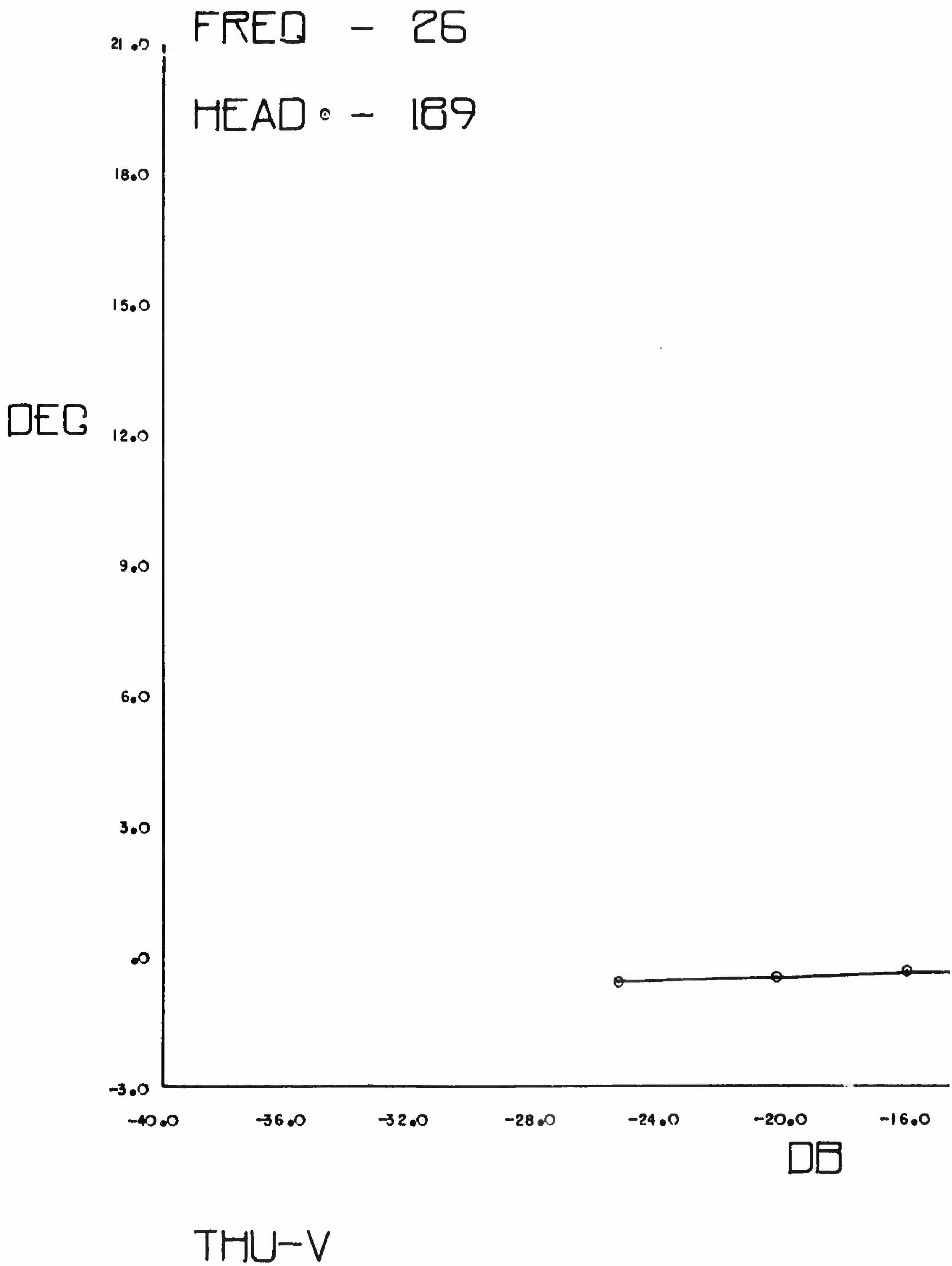


Figure 35. Thule Antenna Patterns - 22 MHz

B


FREQ - 26
HEAD ° - 189
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-40.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
DB
THU-V

A

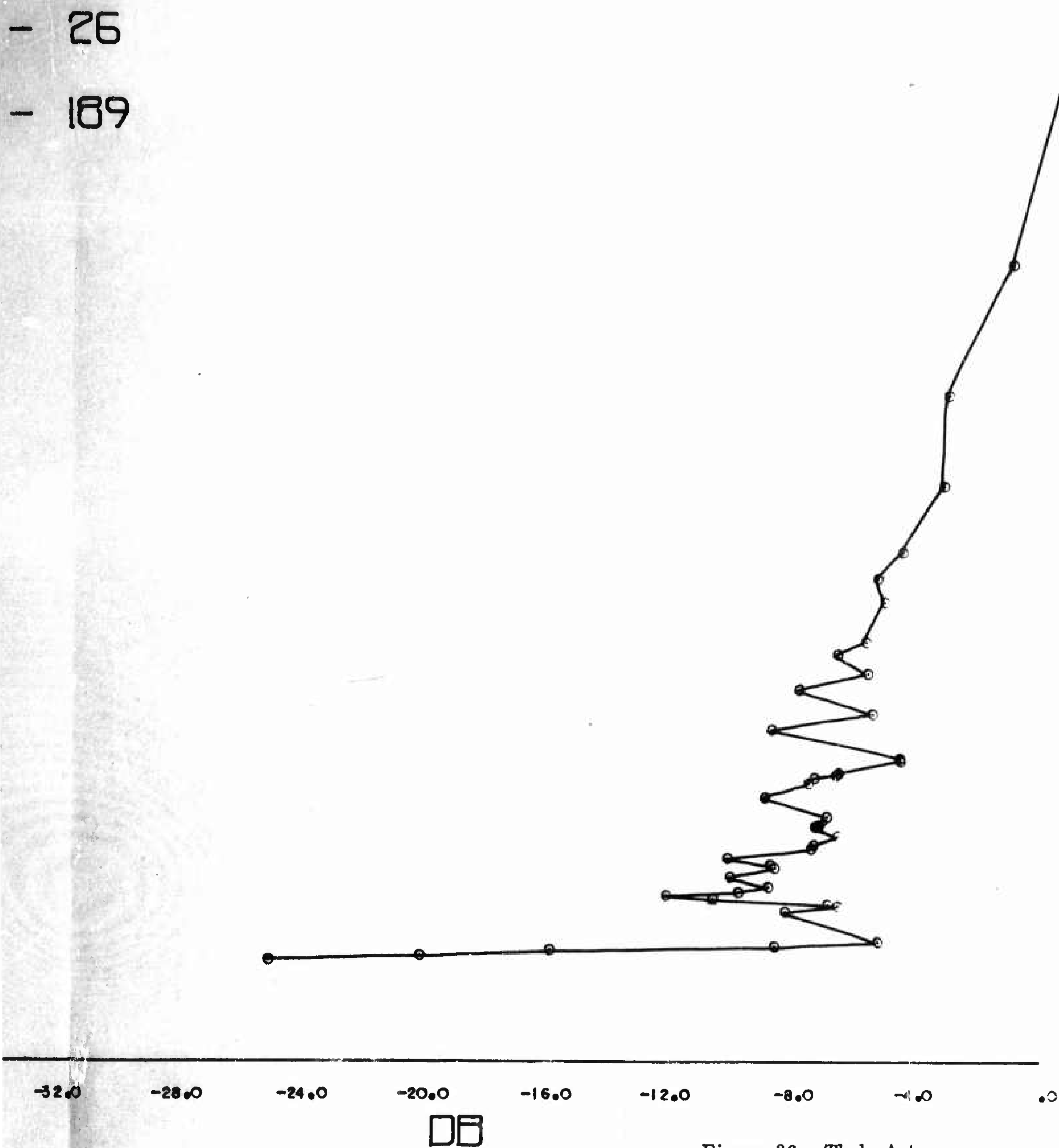
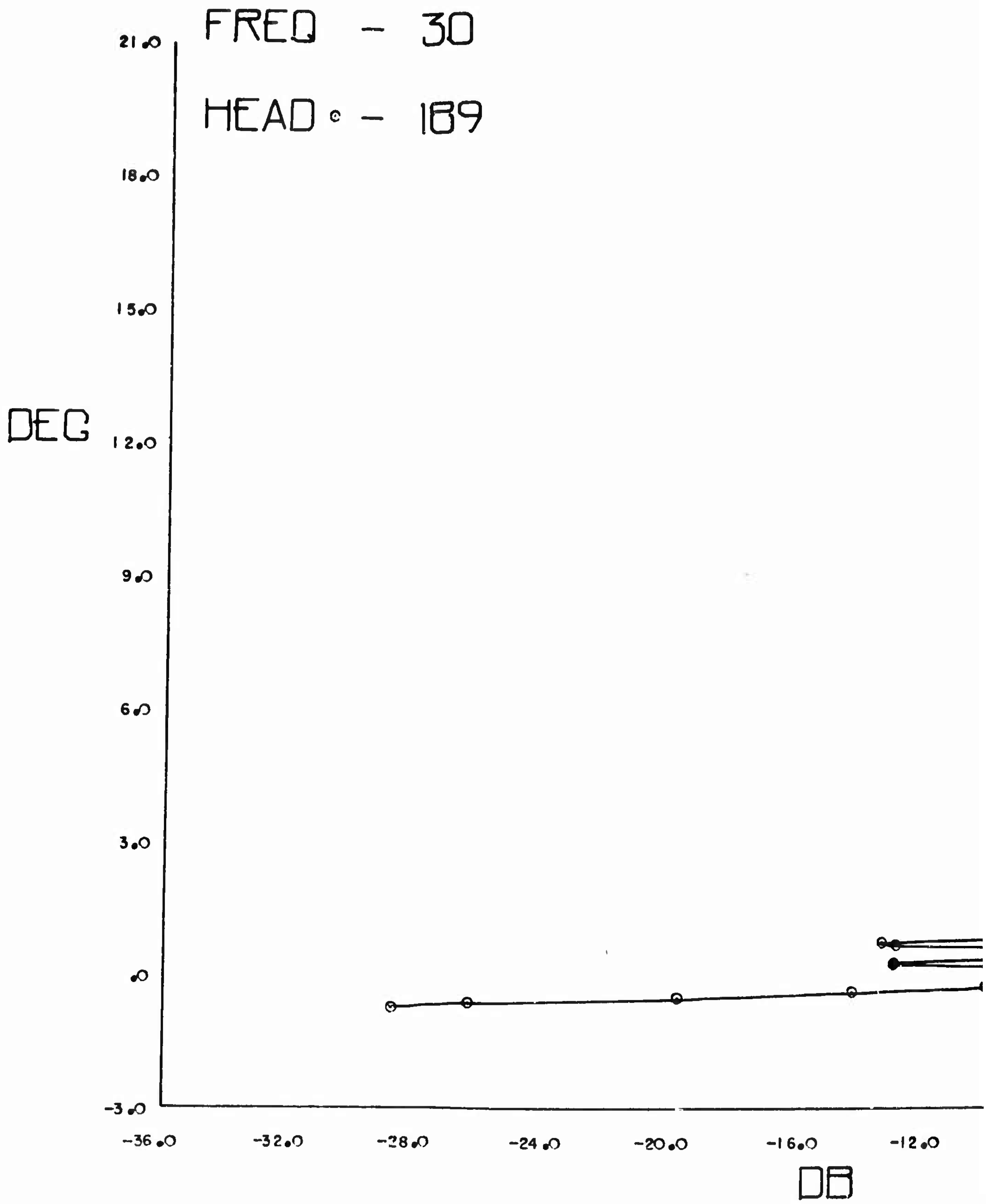


Figure 36. Thule Antenna Patterns - 26 MHz



FREQ - 30
HEAD° - 189
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-36.0
-32.0
-28.0
-24.0
-20.0
-16.0
-12.0
DB

A

THU-V

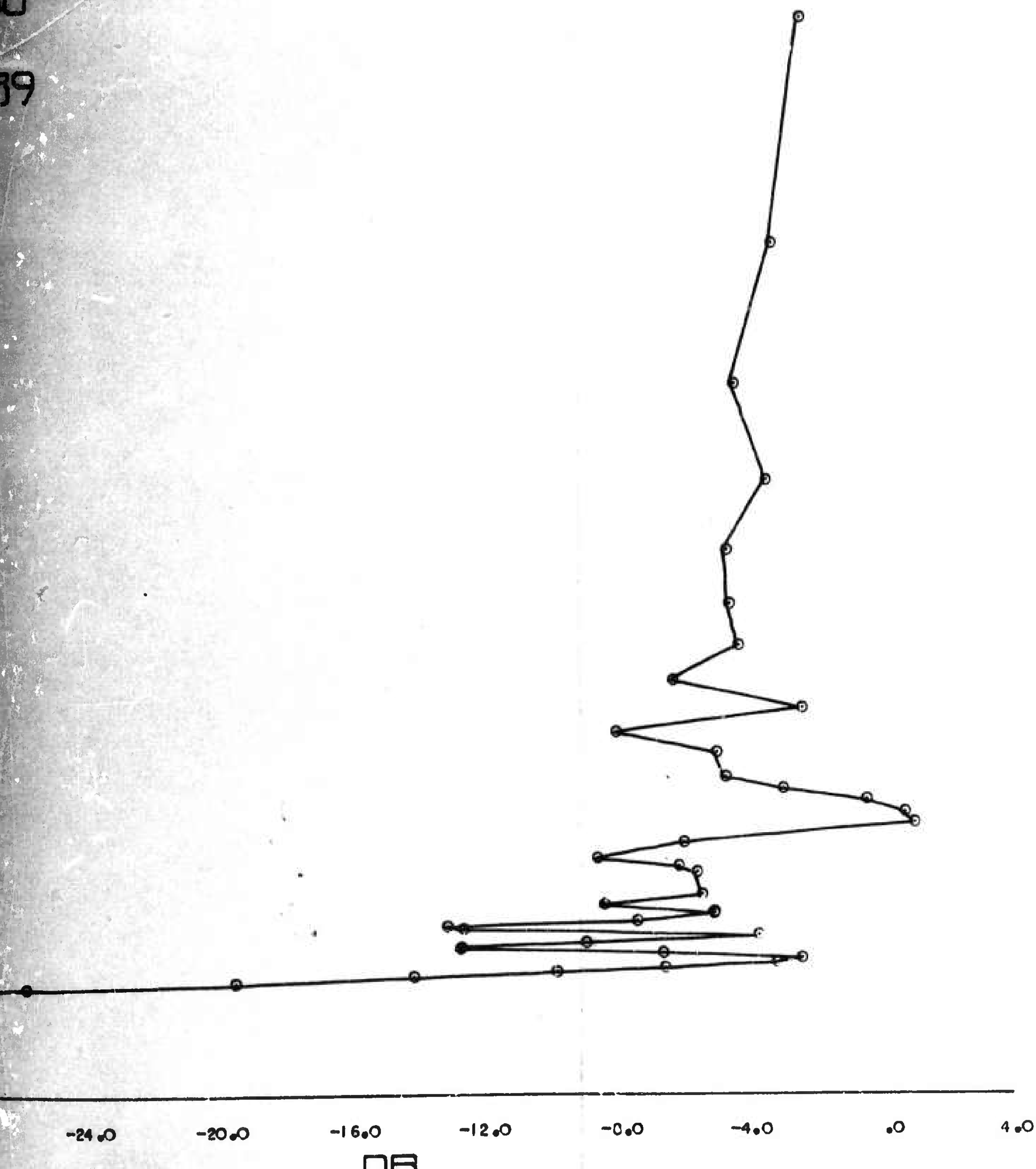
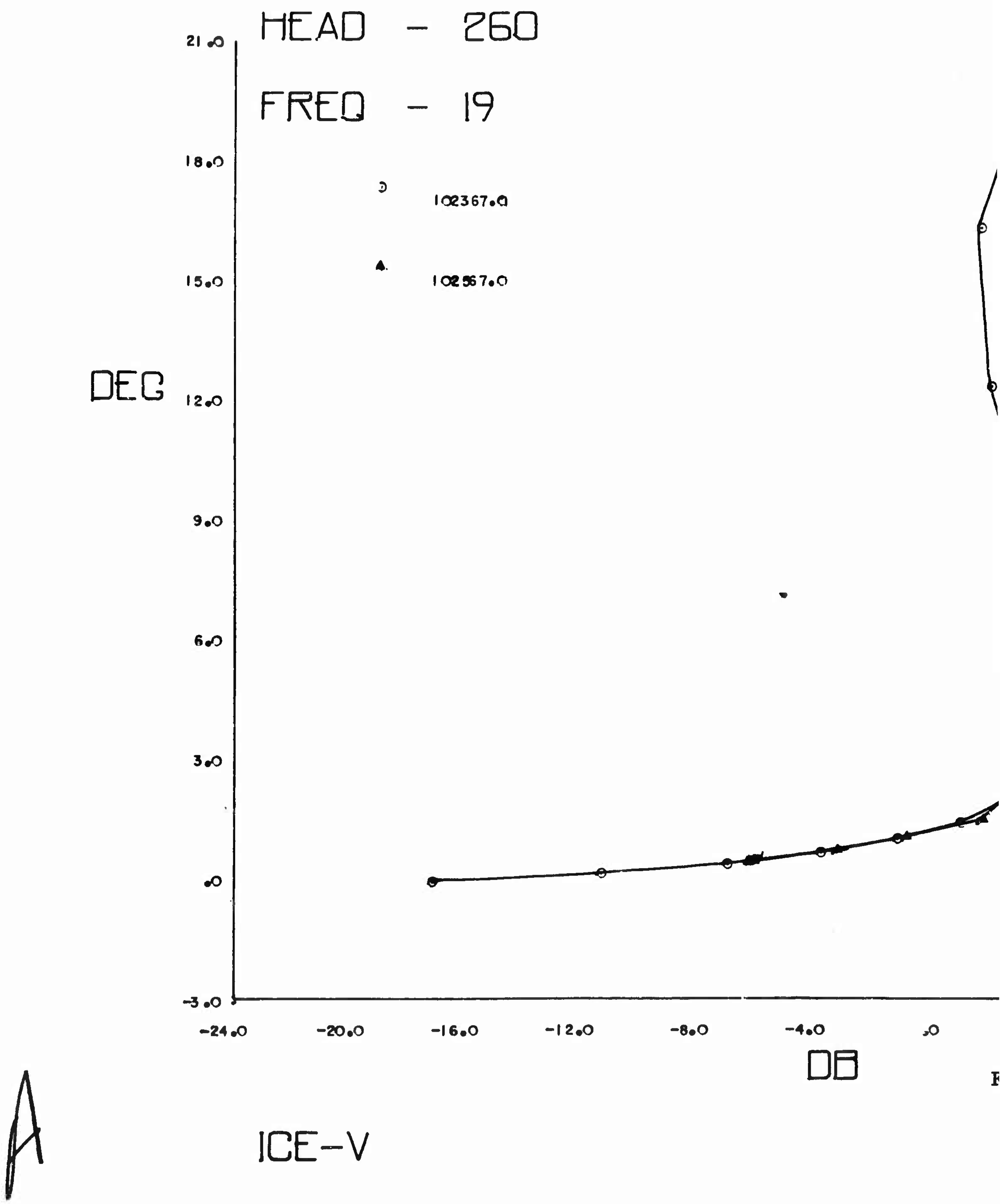


Figure 37. Thule Antenna Patterns - 30 MHz

B


HEAD - 260
FREQ - 19
102367.0
102567.0
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB
A
ICE-V

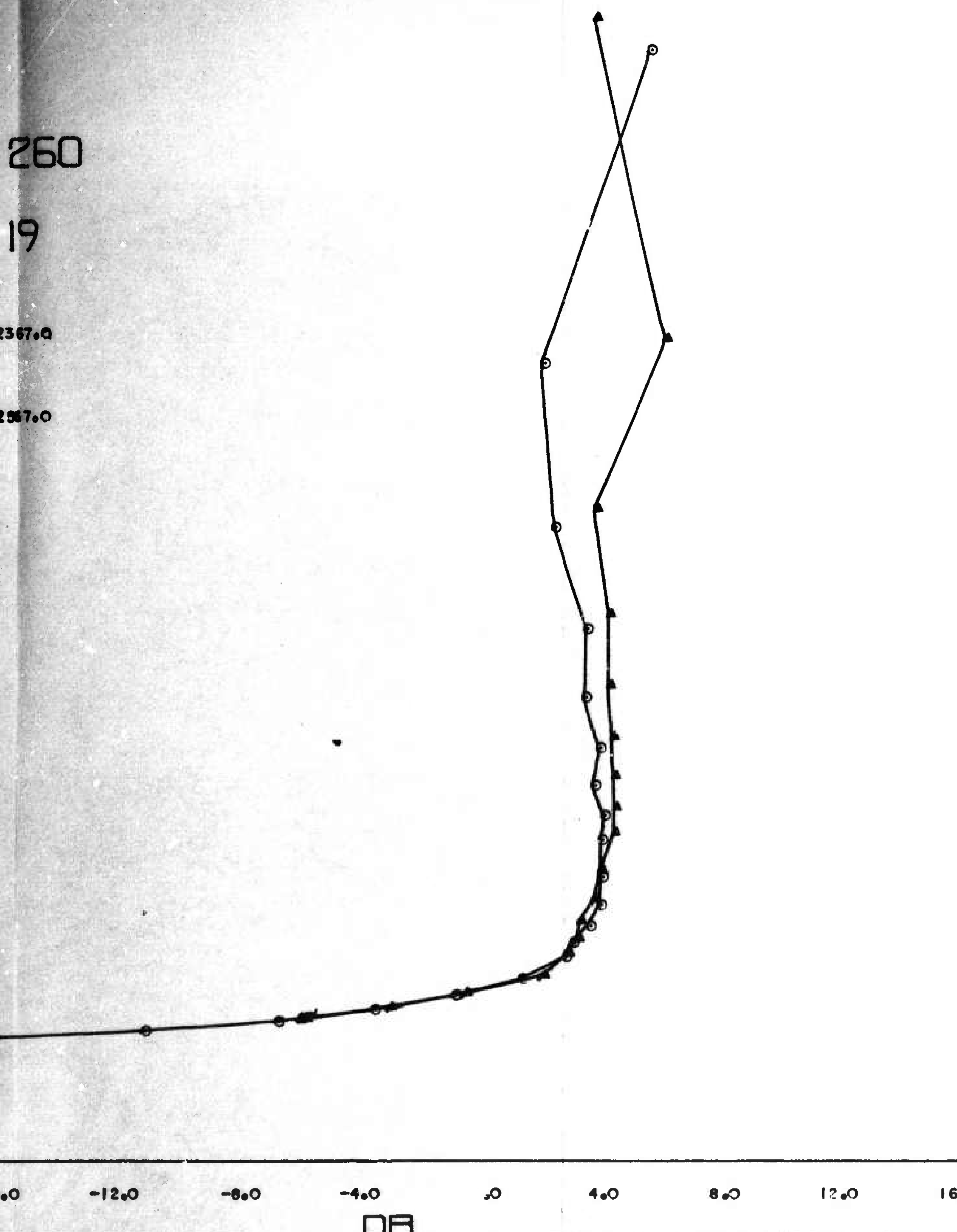
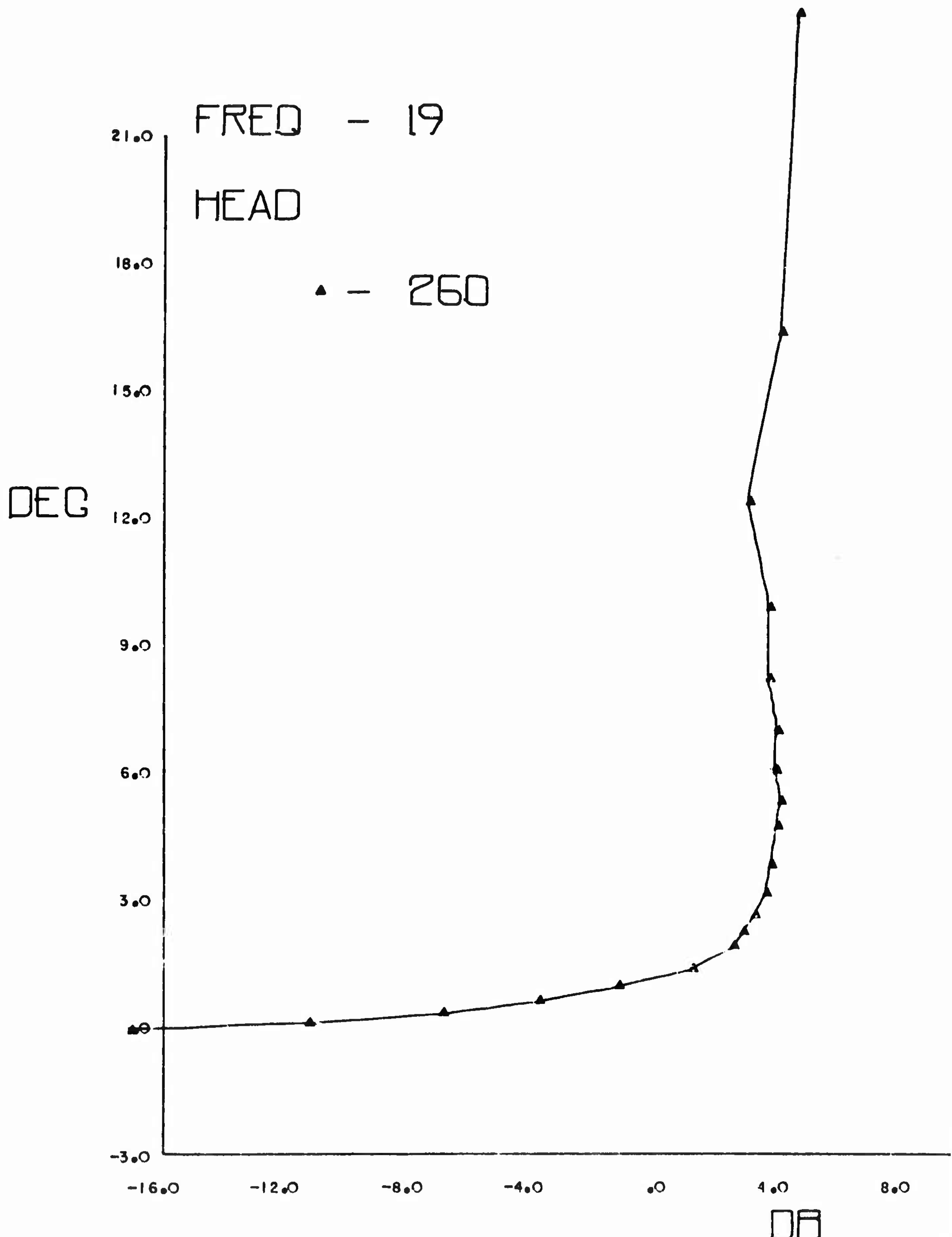


Figure 38. Program TAPPLT - Plot Output (Iceland - 19 MHz)

B


FREQ - 19
HEAD
▲ - 260
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-16.0
-12.0
-8.0
-4.0
.0
4.0
8.0
DB

A

ICE-V

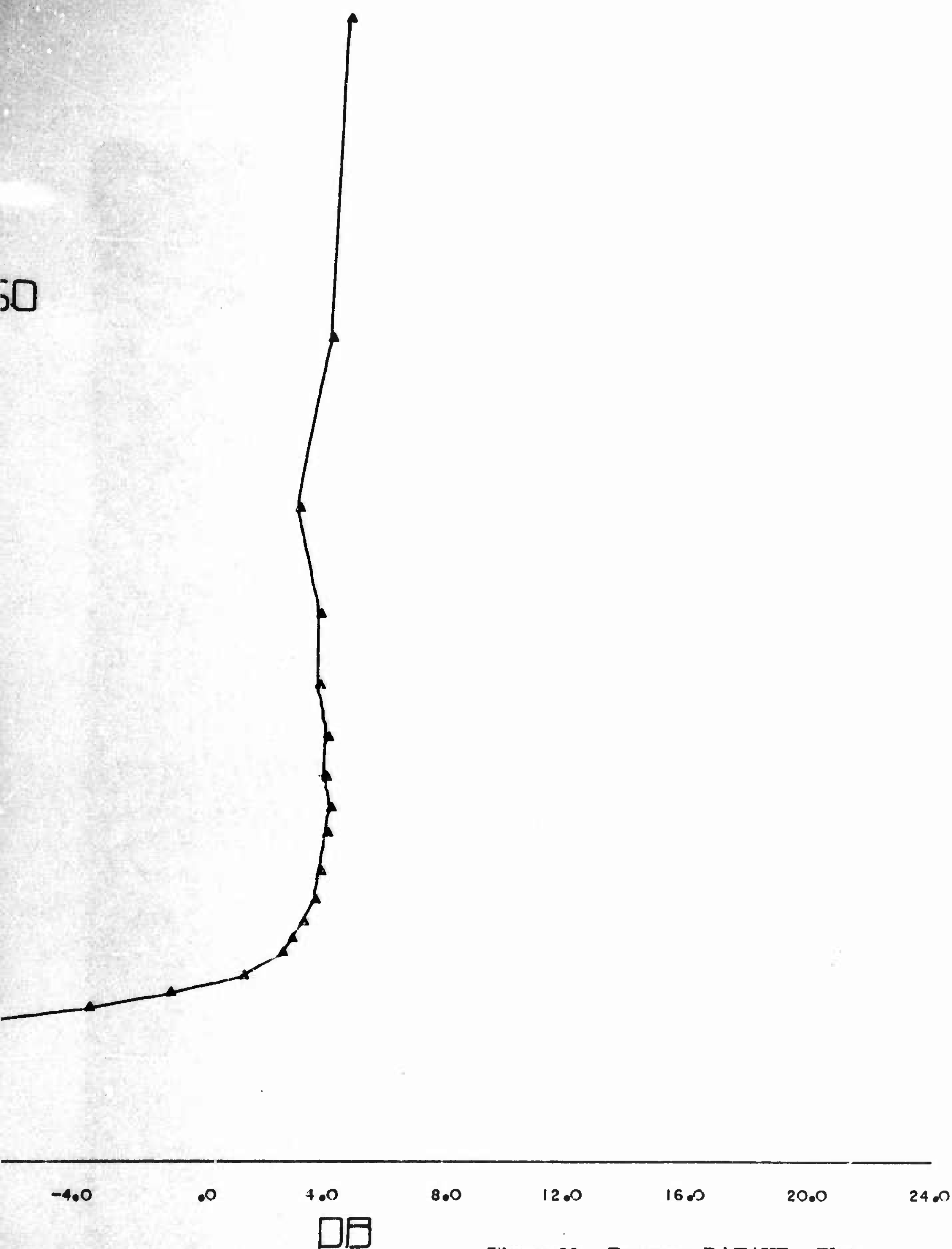
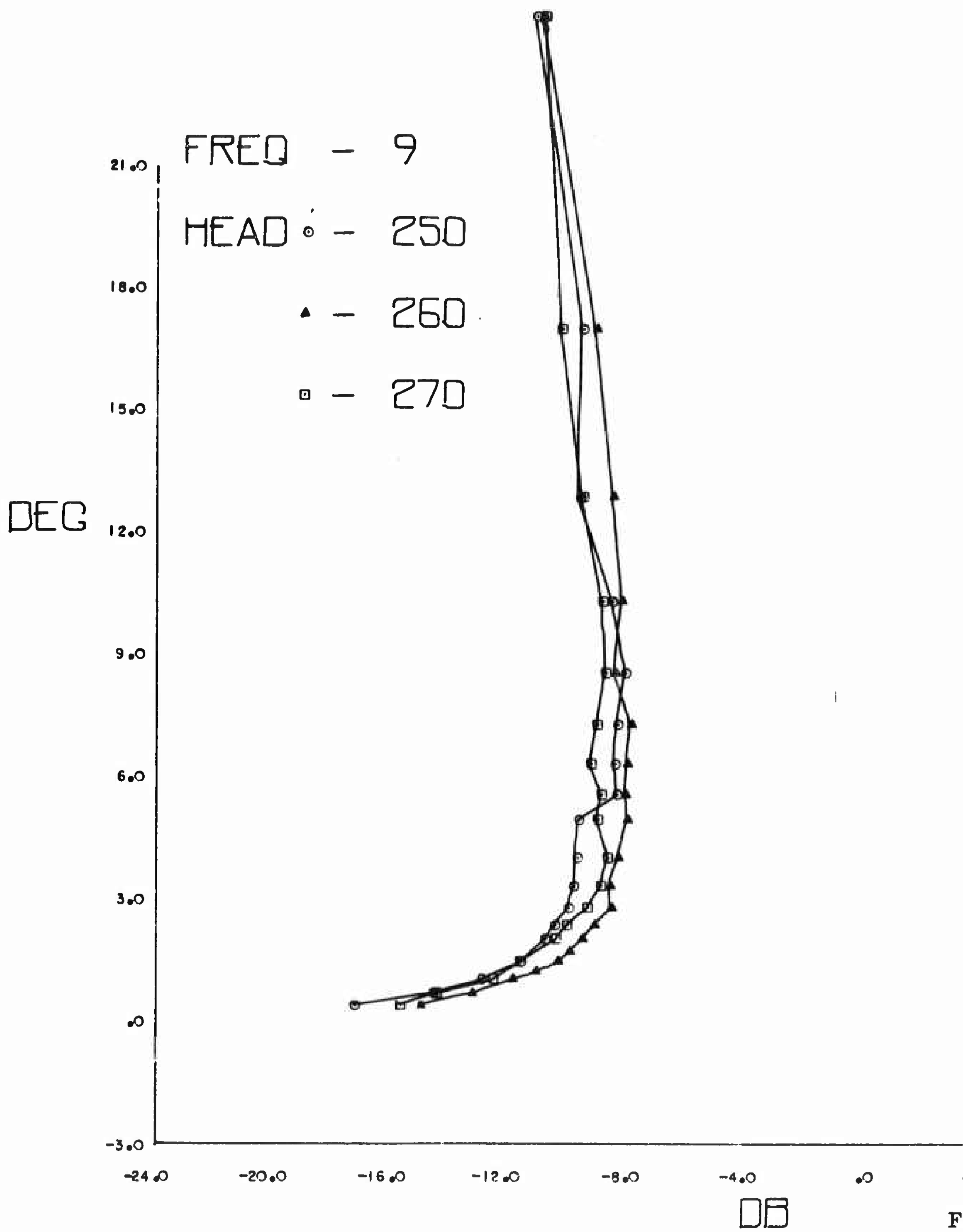


Figure 39. Program DATAVE - Plot Output (Iceland - 19 MHz)

B



FREQ - 9
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB

A

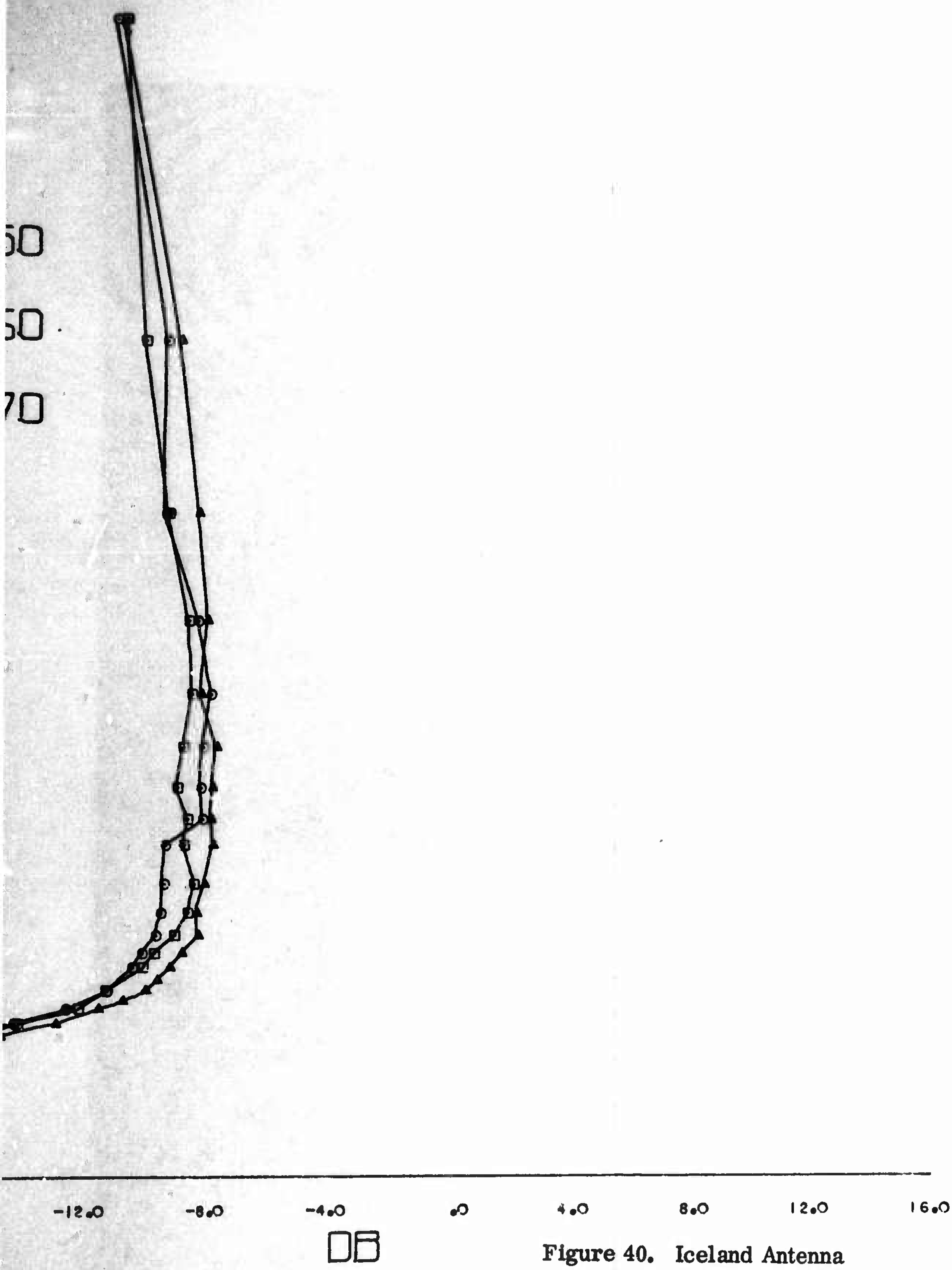


Figure 40. Iceland Antenna Patterns - 9 MHz

B

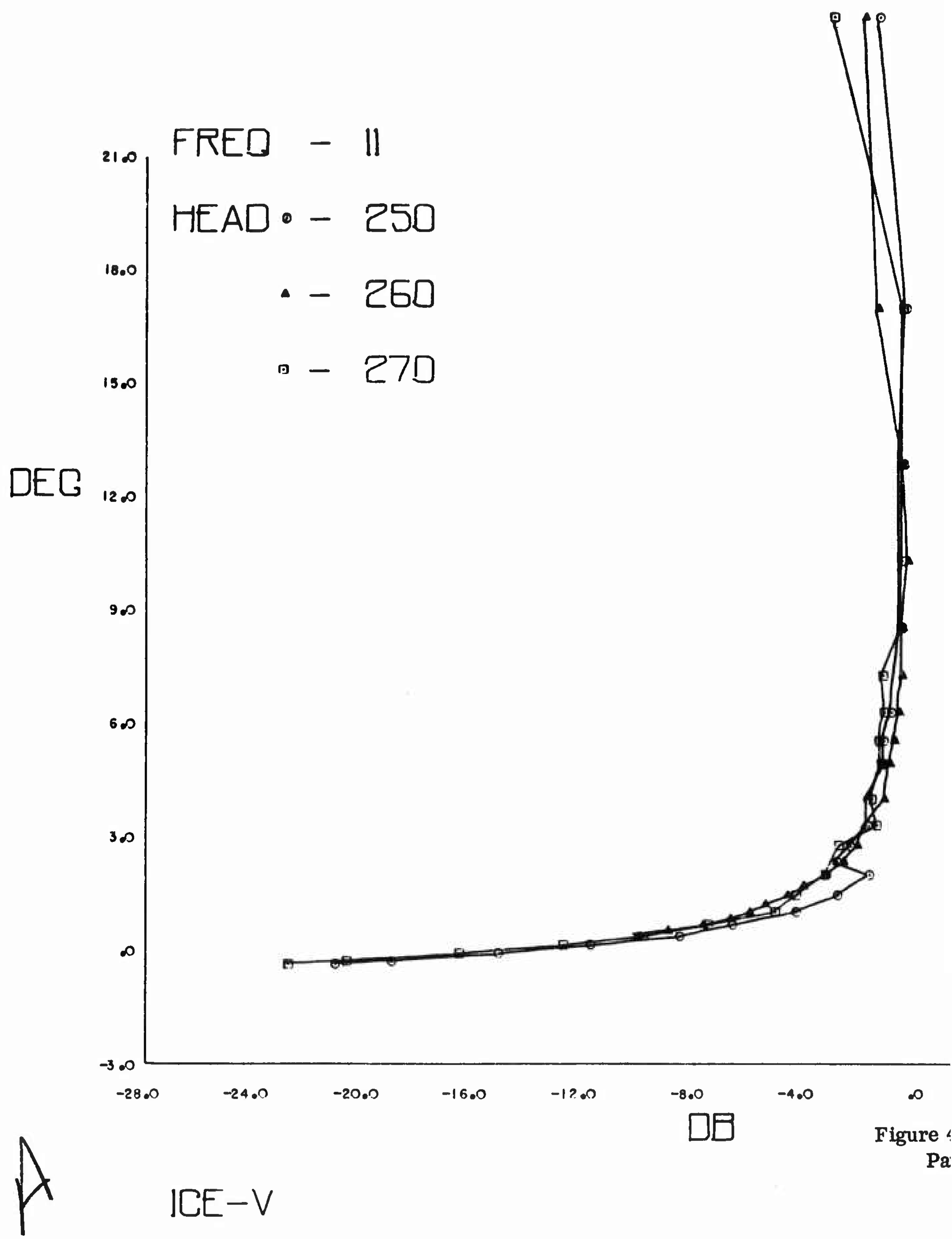

FREQ - 11
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-28.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB
ICE-V

Figure 4
Pa

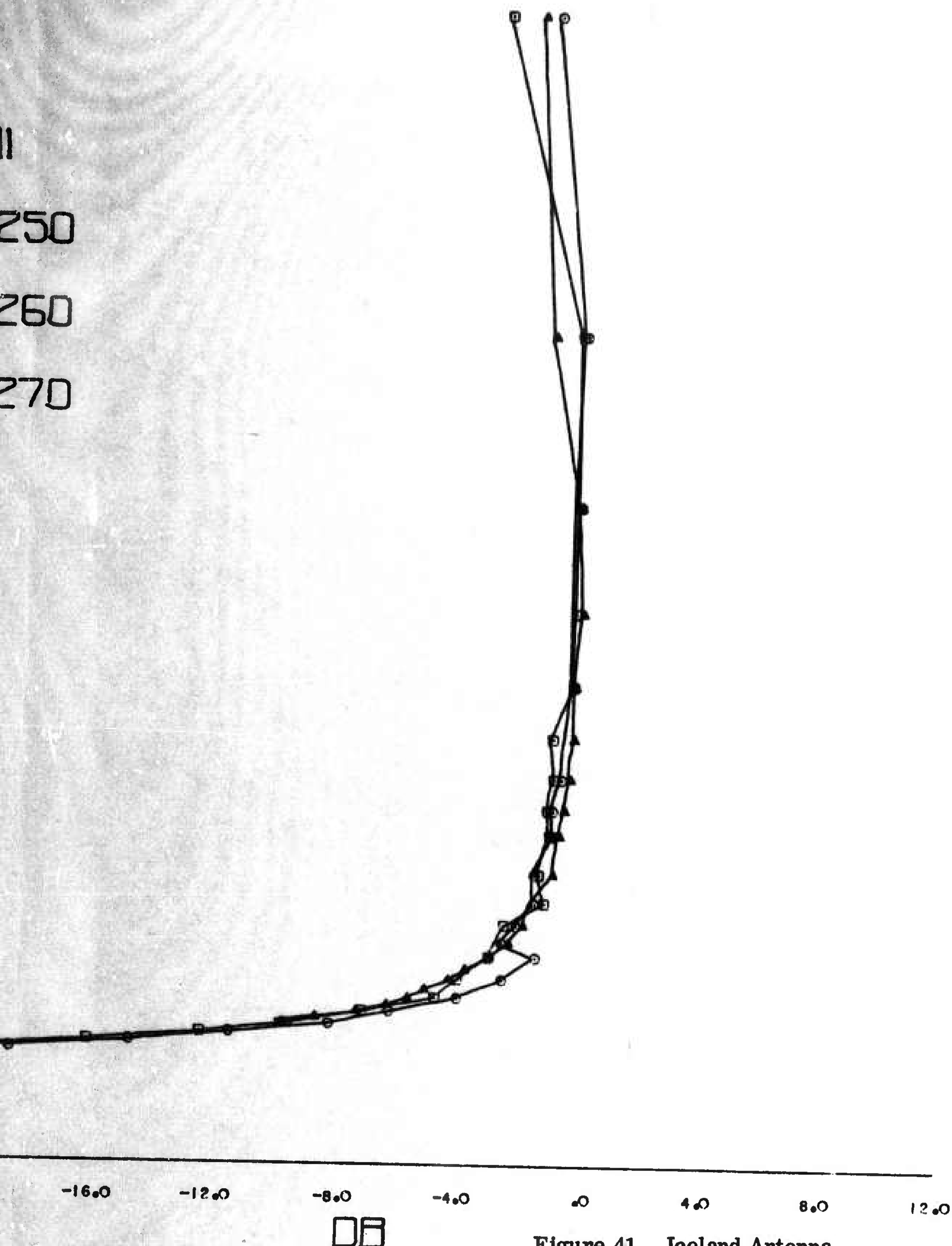
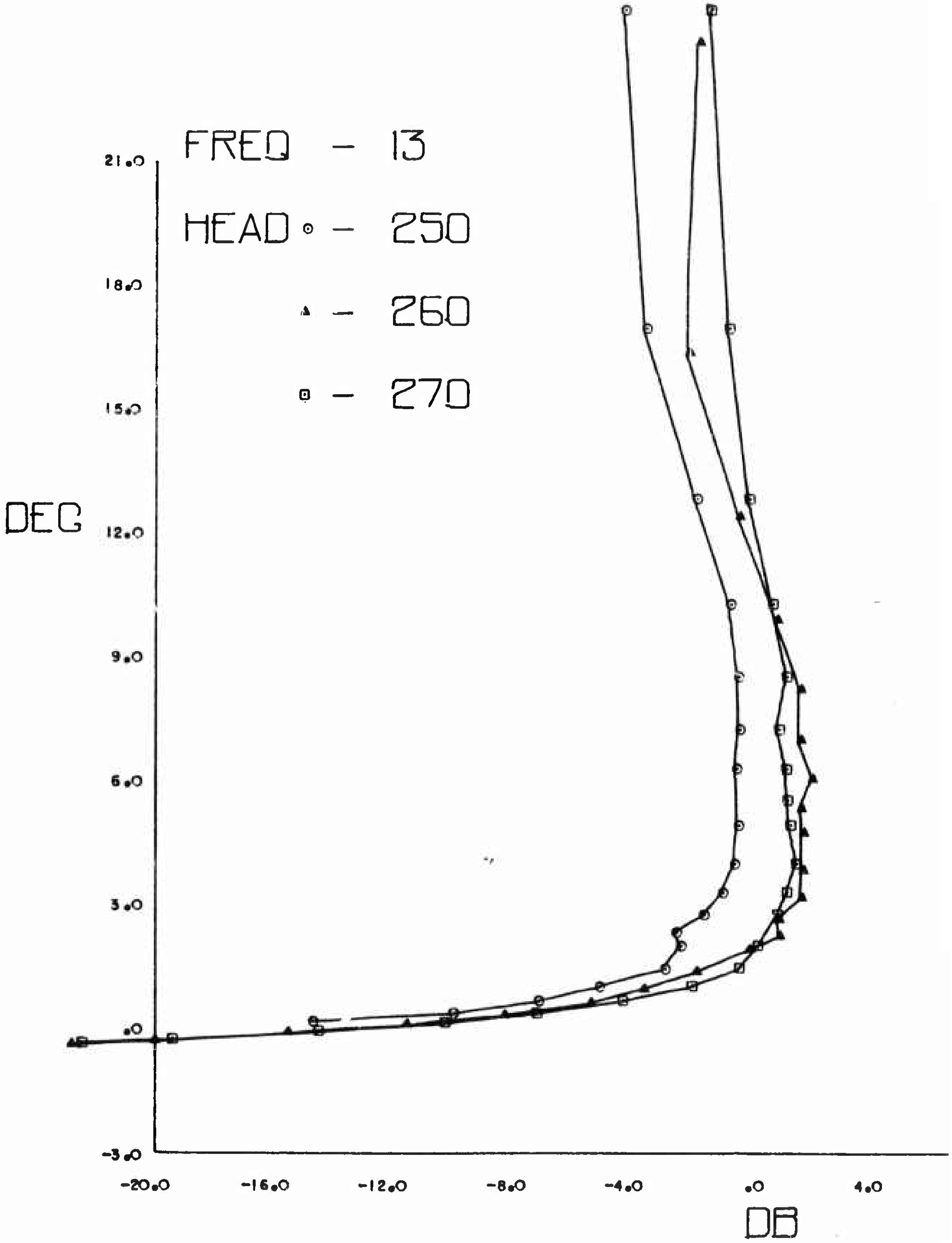


Figure 41. Iceland Antenna
Patterns - 11 MHz

B



FREQ - 13
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
4.0
DB

ICE-V

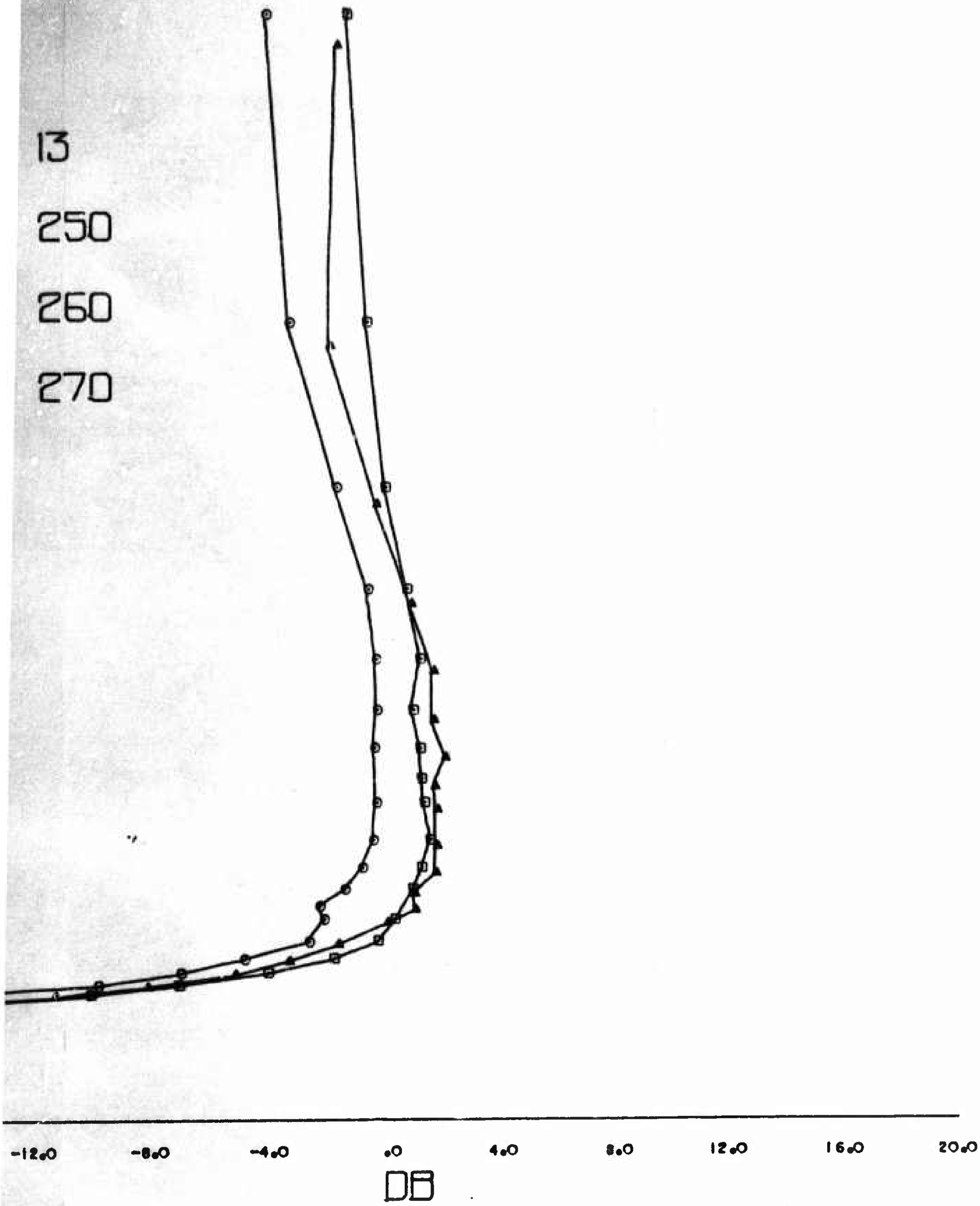
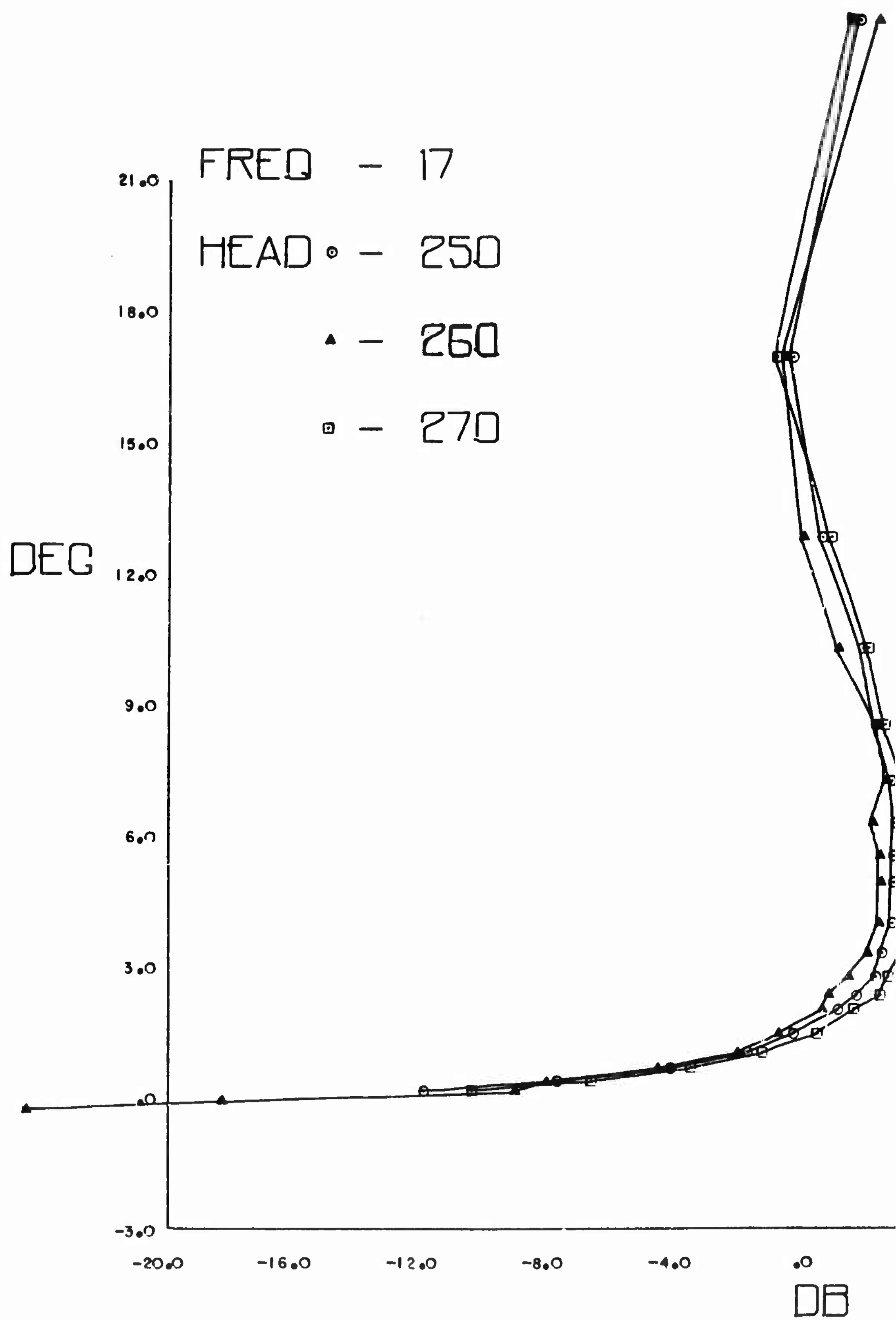


Figure 42. Iceland Antenna
Patterns - 13 MHz

B


FREQ - 17
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB

ICE-V

A

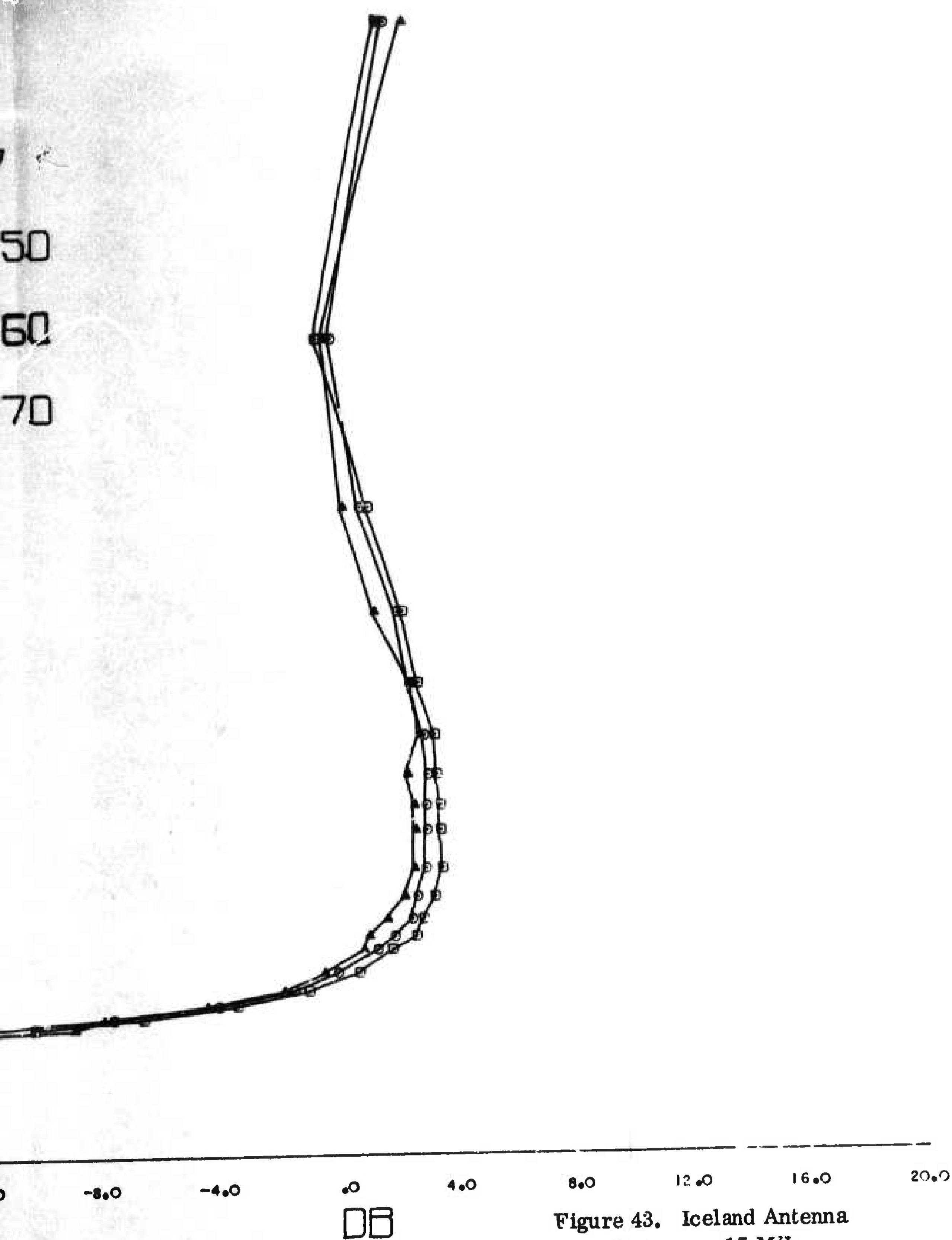
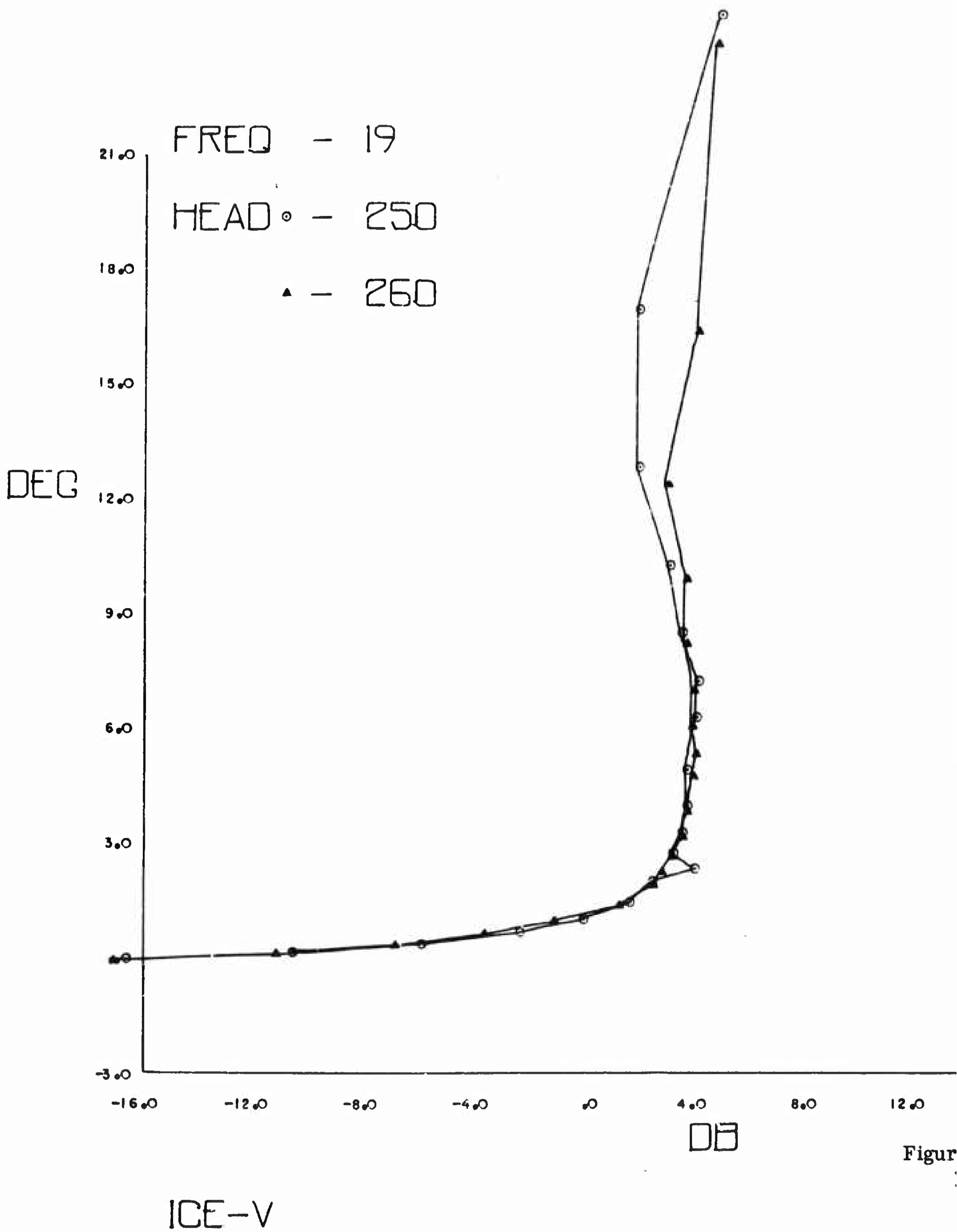


Figure 43. Iceland Antenna
Patterns - 17 MHz

B


FREQ - 19
HEAD ⊙ - 250
▲ - 260
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
0.0
-3.0
-16.0
-12.0
-8.0
-4.0
.0
4.0
8.0
12.0
DB
ICE-V

Figur

A

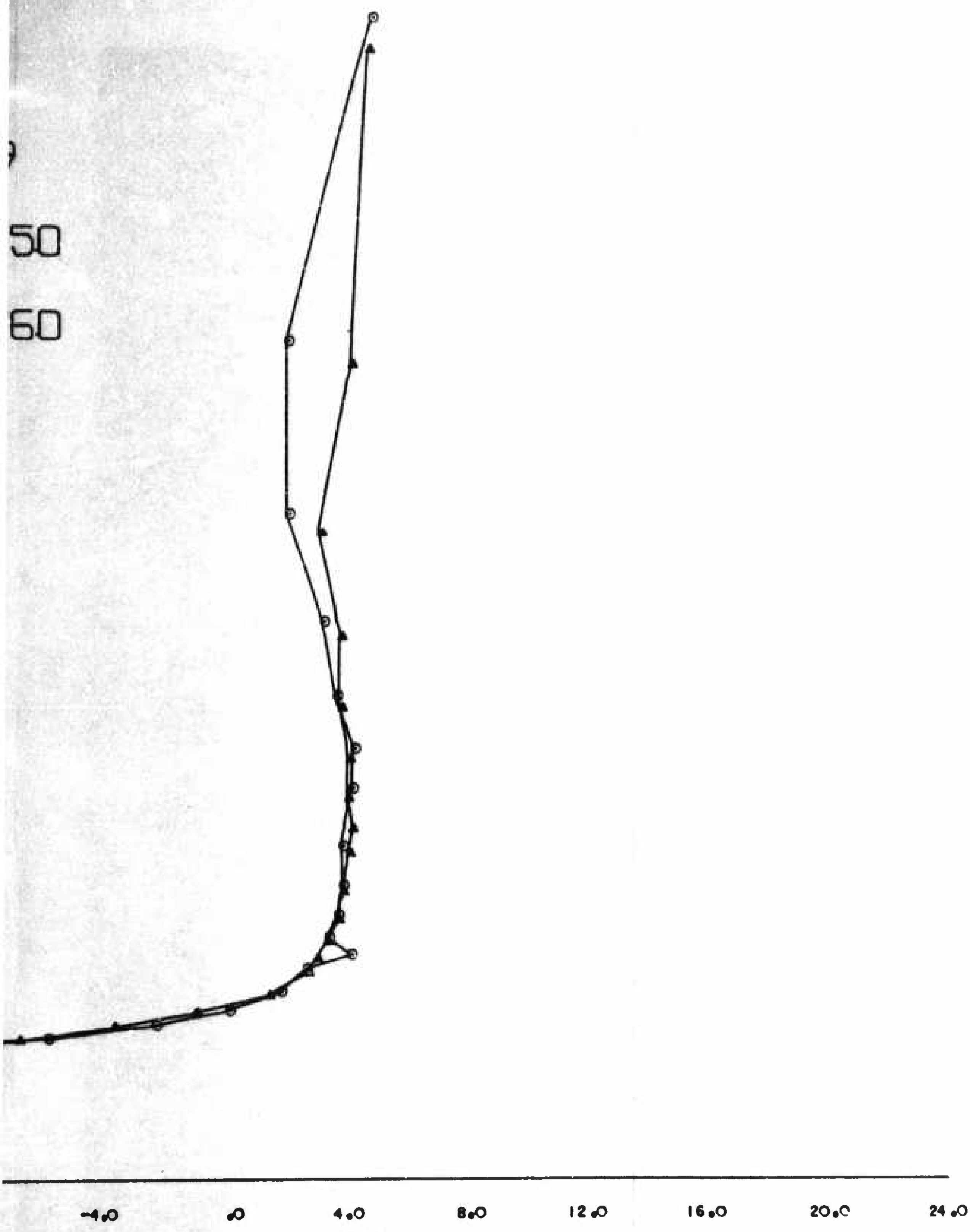
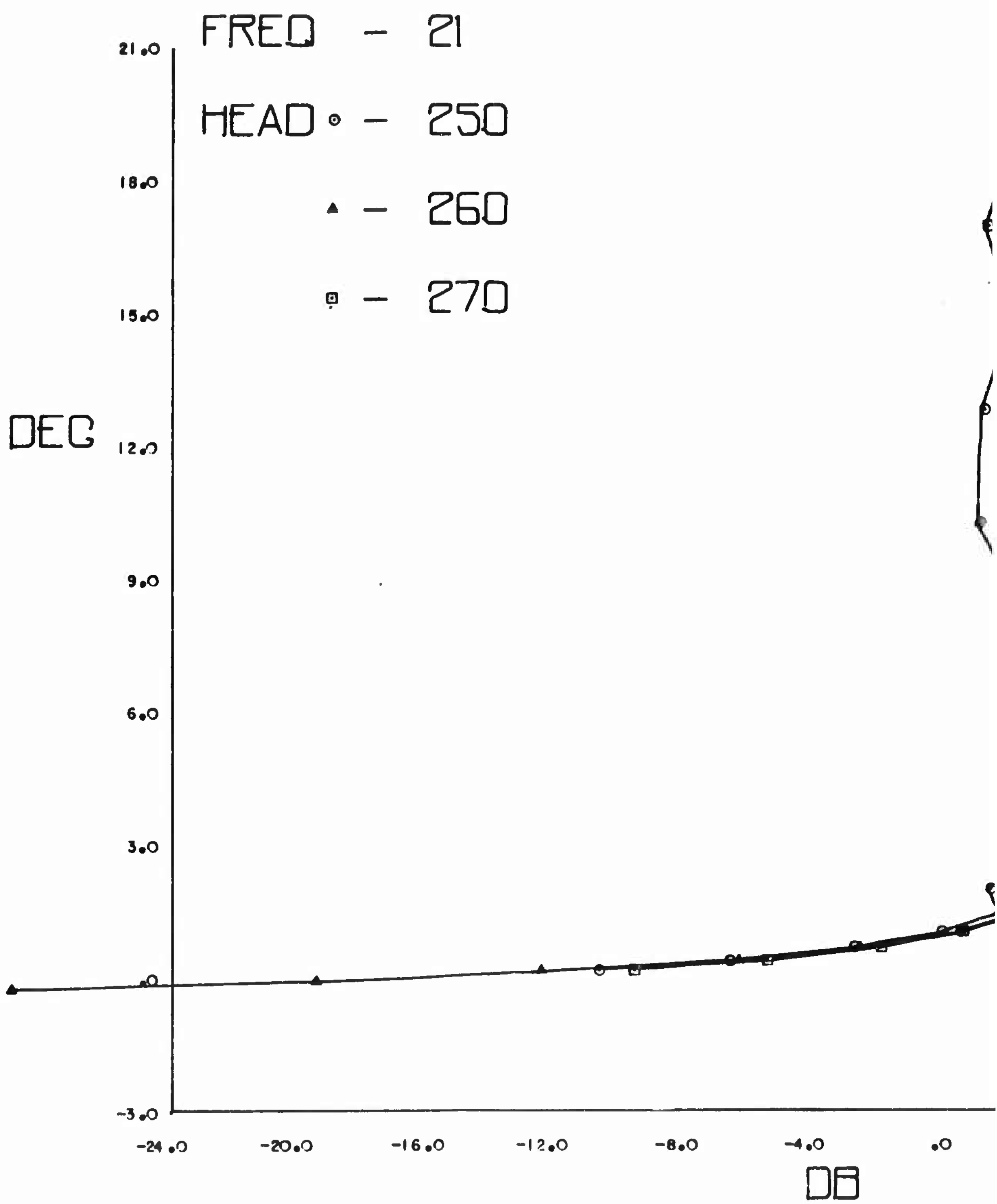


Figure 44. Iceland Antenna Patterns - 19 MHz

B


FREQ - 21
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB

A

ICE-V

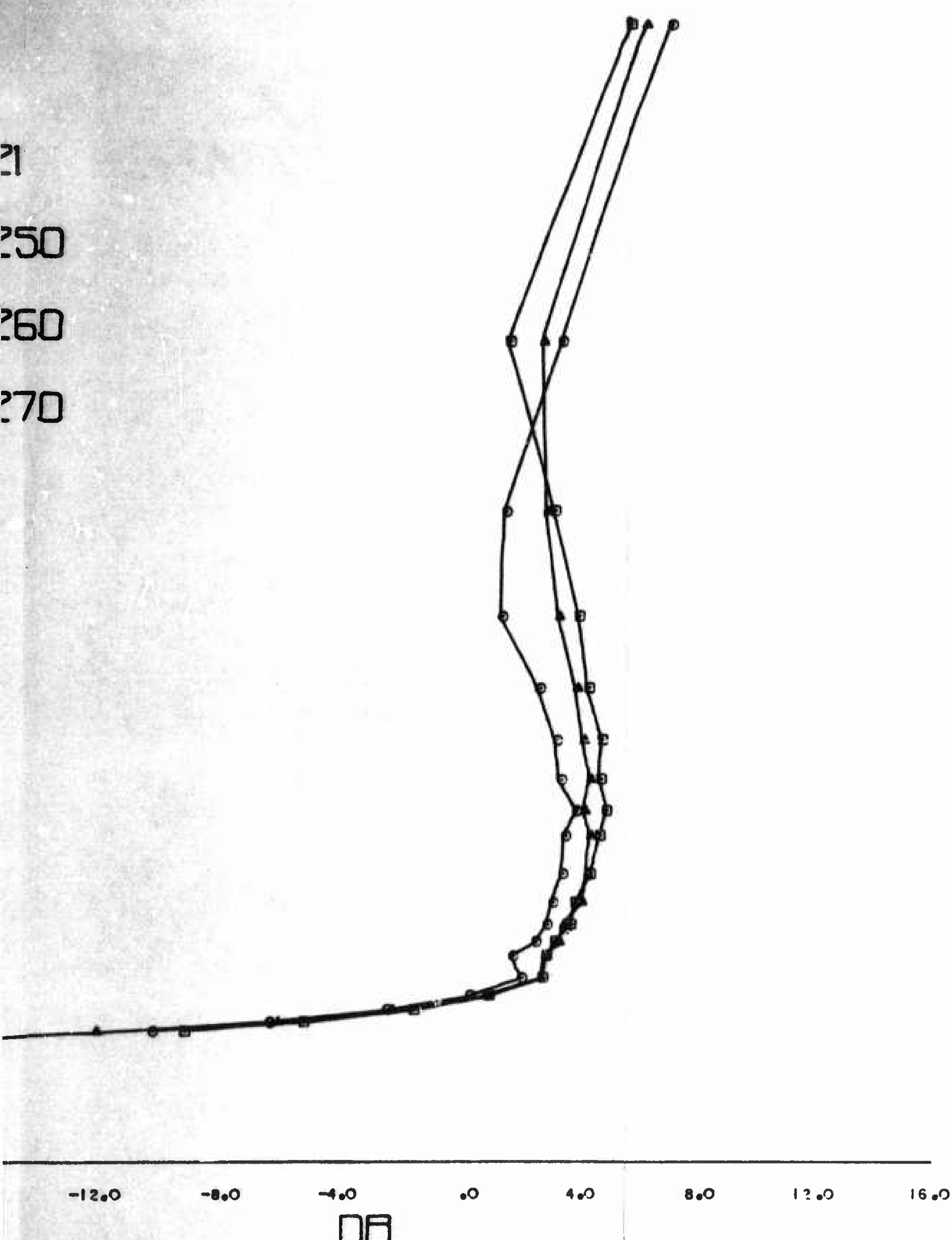
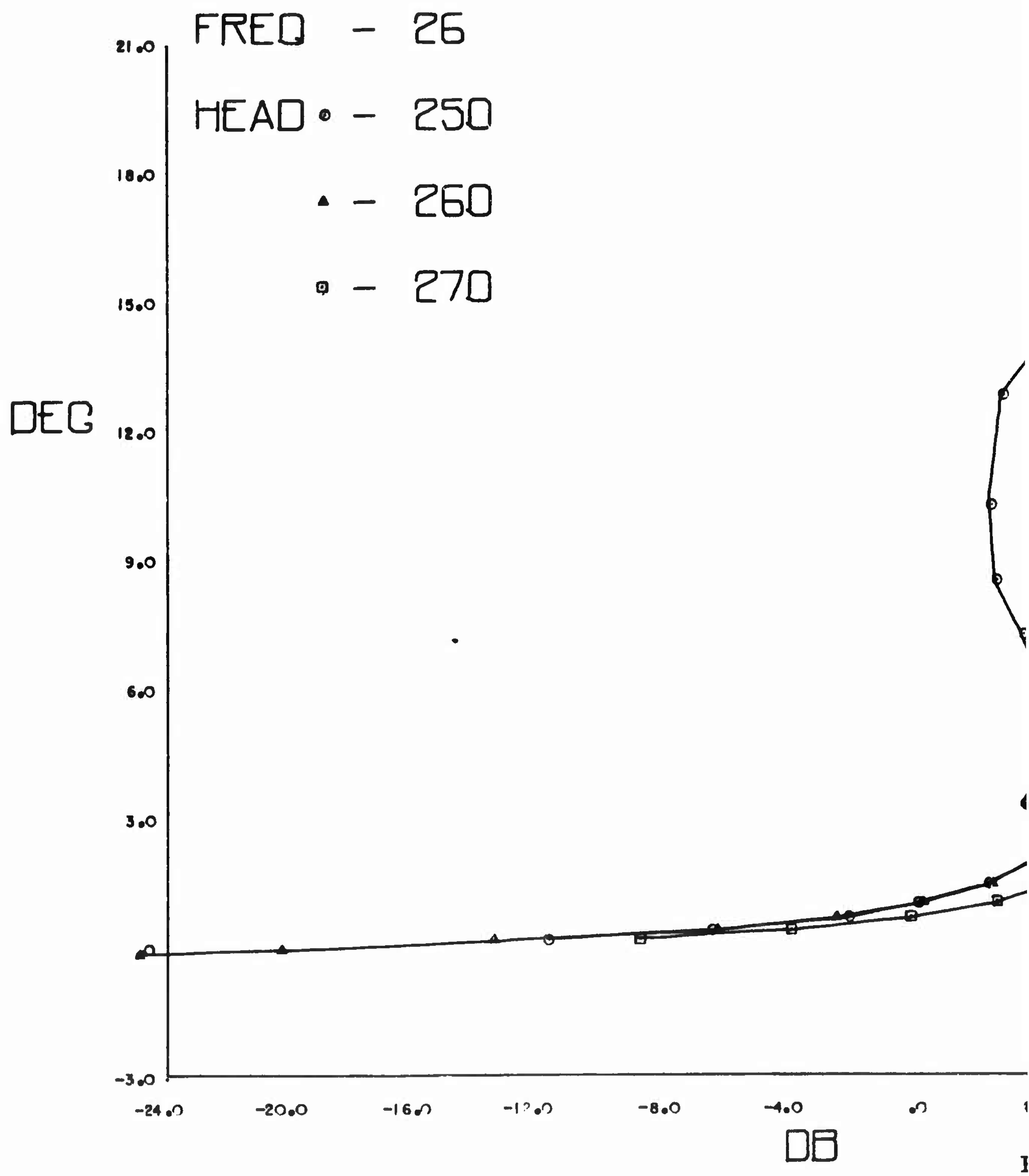


Figure 45. Iceland Antenna Patterns - 21 MHz


FREQ - 26
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
-3.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
DB

A

ICE-V

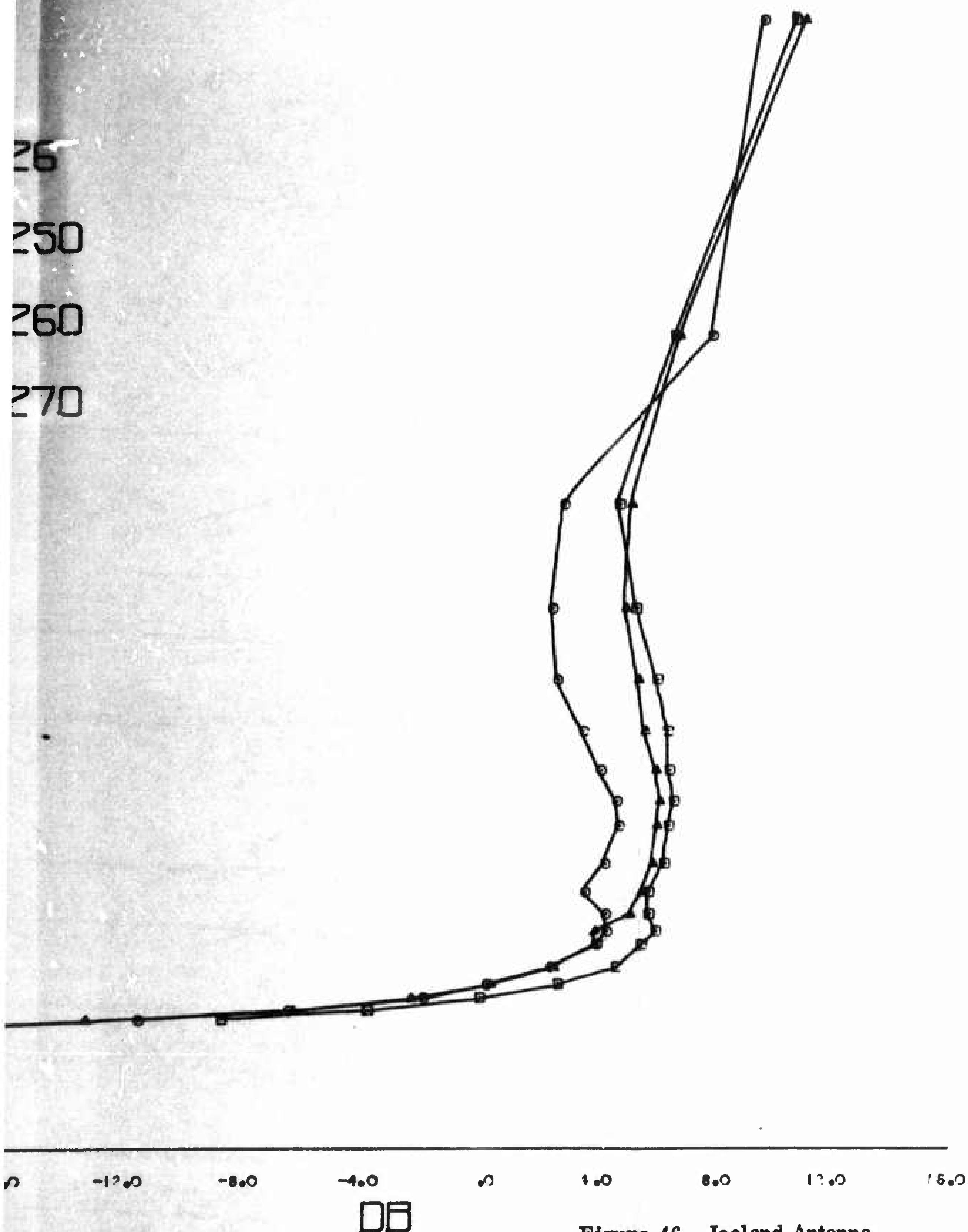
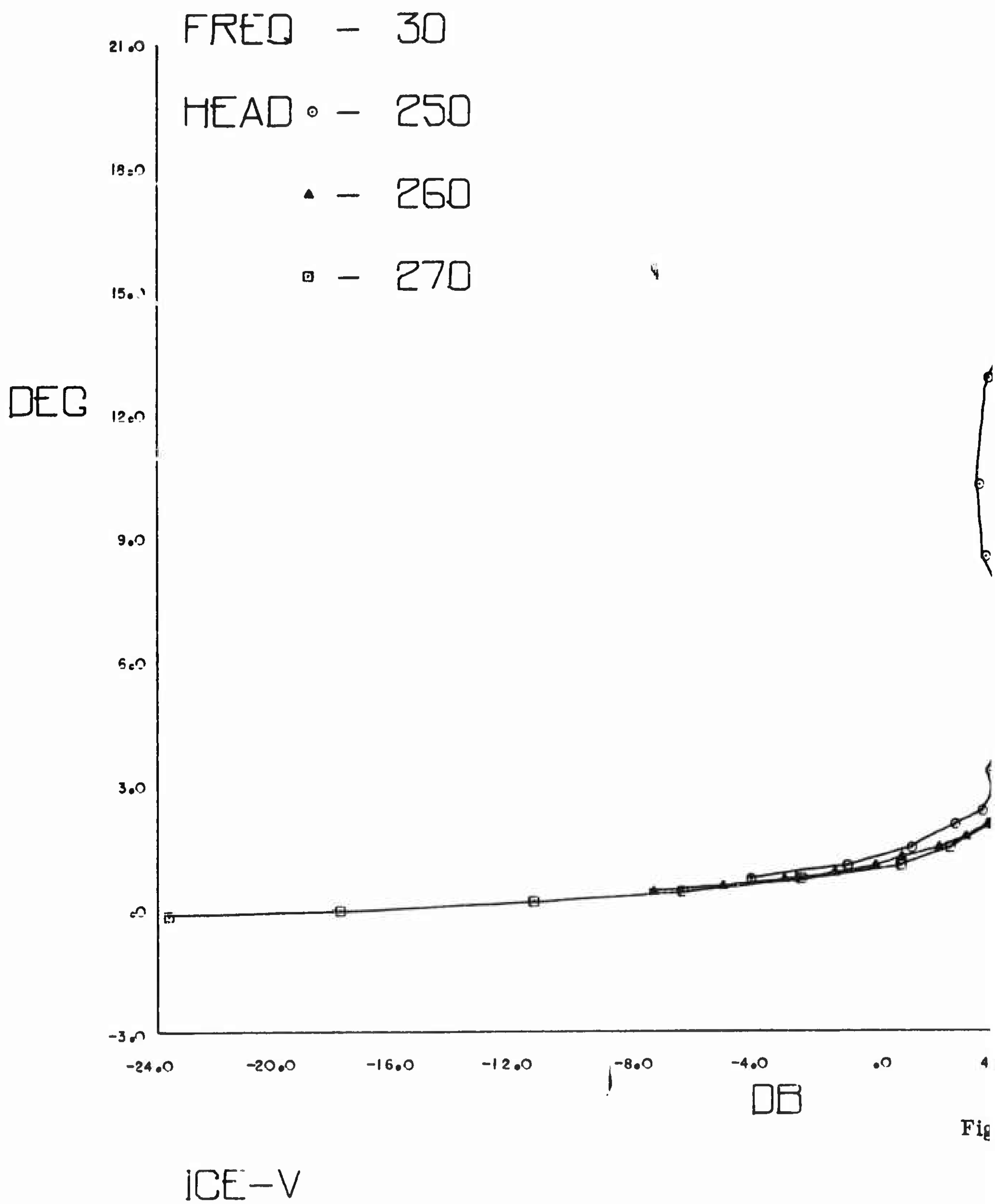


Figure 46. Iceland Antenna Patterns - 26 MHz

B


FREQ - 30
HEAD ⊙ - 250
▲ - 260
⊡ - 270
DEG
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
-24.0
-20.0
-16.0
-12.0
-8.0
-4.0
.0
4
DB
ICE-V

Fig

A

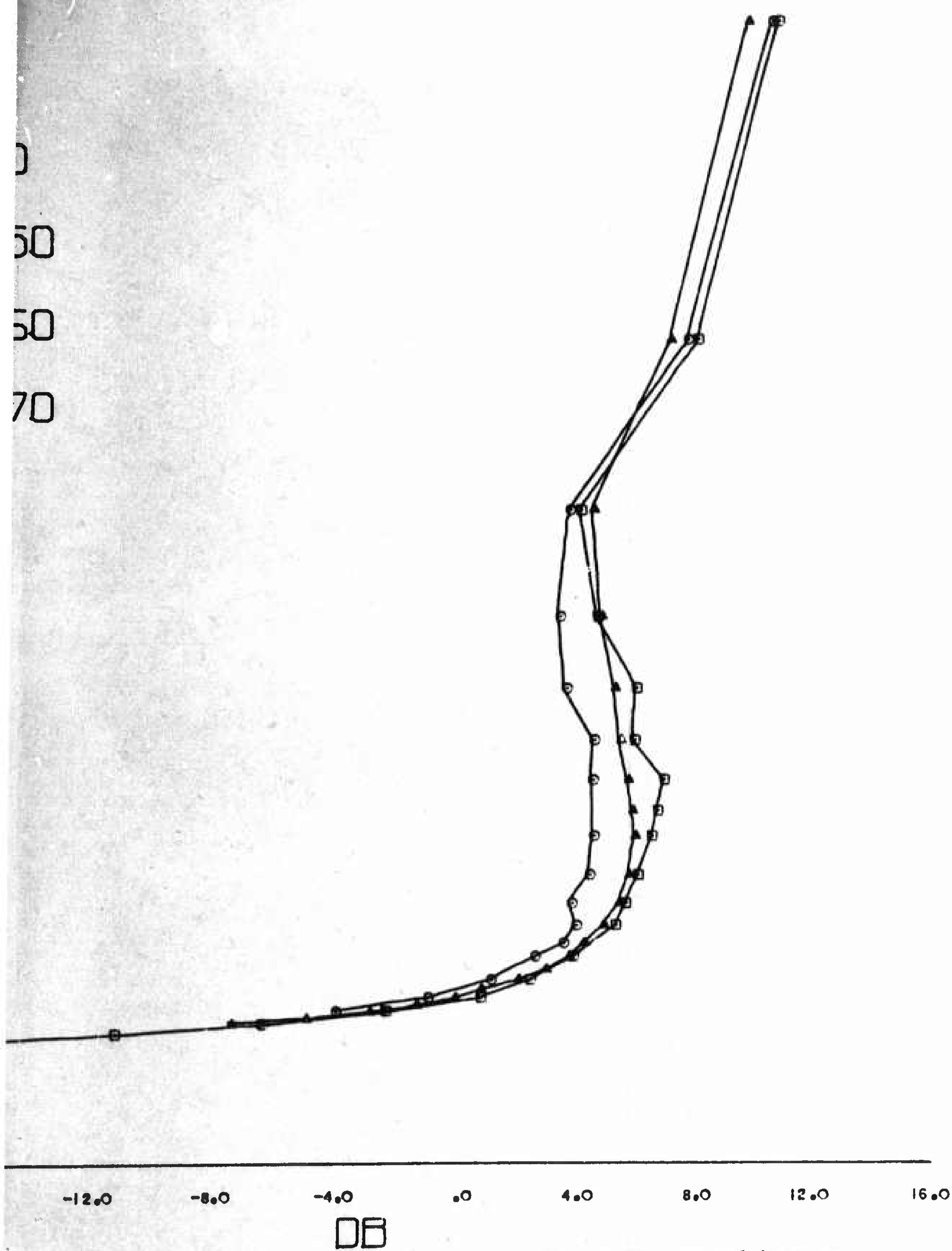
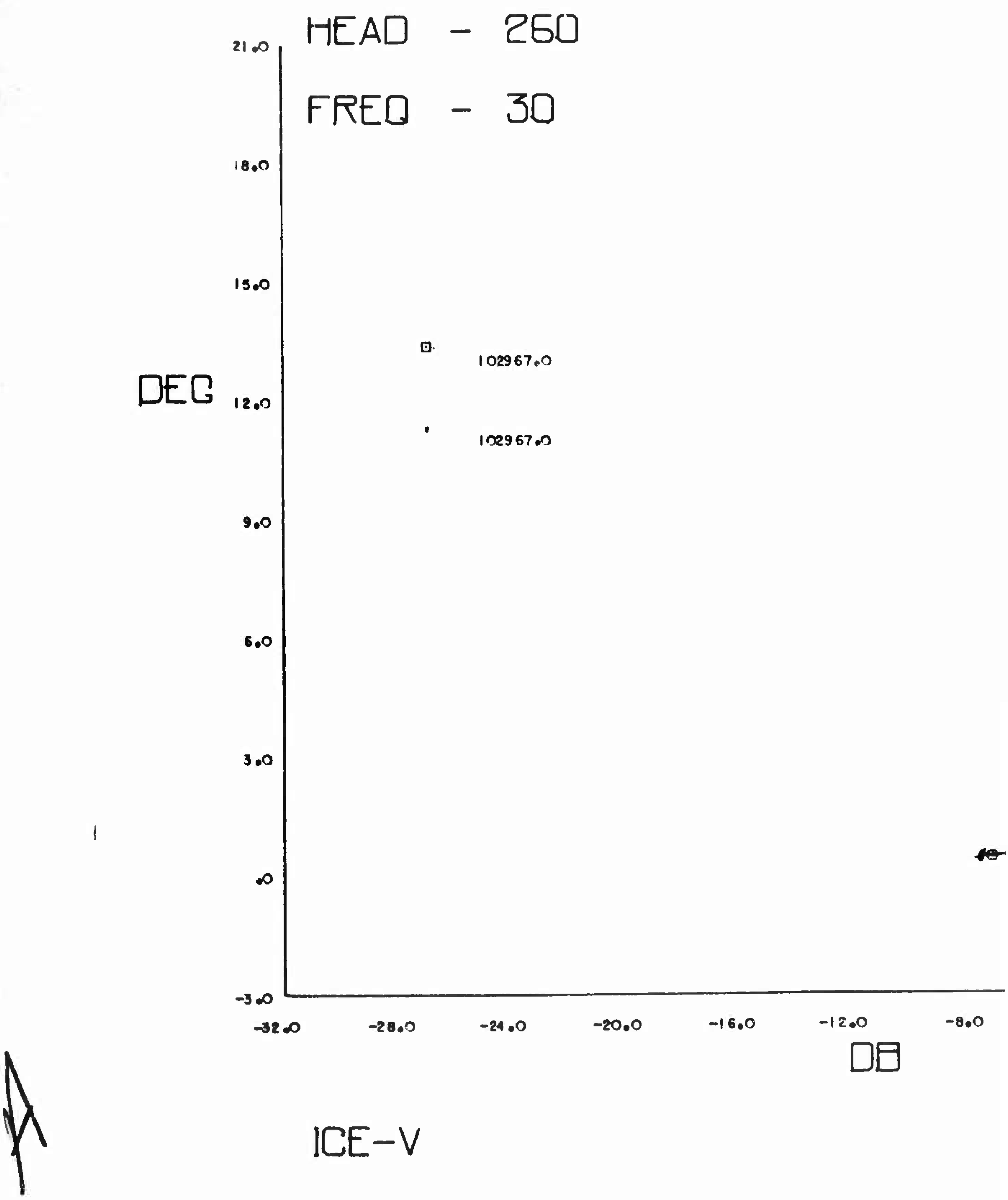


Figure 47. Iceland Antenna Patterns - 30 MHz

B

It was discovered that the Iceland antenna pattern data was subject to tidal effects. Figure 48 shows two data runs flown on the same day, the first at high tide and the second at low tide. The difference in water level between these two cases is approximately eight feet. These variances in the pattern are too large to be disregarded. Before utilizing these data, a method must be derived accounting for these effects. The simplest method would be to obtain an average gain and then consider the tide effects as a perturbation on this average.



HEAD - 260
FREQ - 30
21.0
18.0
15.0
12.0
9.0
6.0
3.0
.0
-3.0
DEG
102967.0
102967.0
-32.0
-28.0
-24.0
-20.0
-16.0
-12.0
-8.0
DB
ICE-V

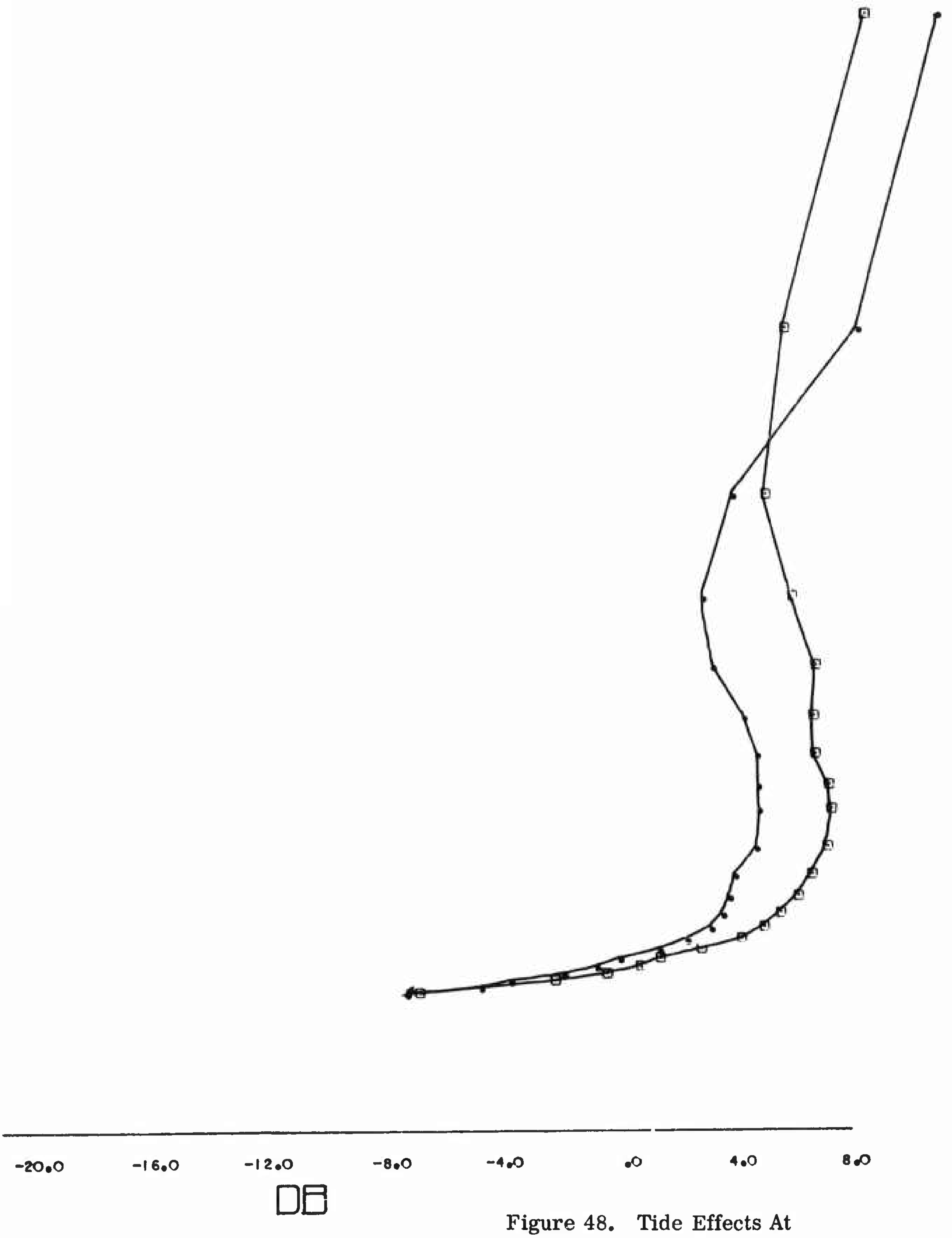


Figure 48. Tide Effects At
Iceland - 30 MHz

B

VIII. FUTURE CONSIDERATIONS

The gain measurements of the antennas at the Starr Hill receive site have not been completed. The measurement technique discussed herein will be employed, and it is intended that this phase of the program be completed during the spring and summer of 1968. In addition, the calibration of the aircraft loop antenna, required to obtain absolute gain, will be accomplished during this same period.

A calibration of the azimuth of arrival measurement system (antennas and equipment) located at Starr Hill is tentatively scheduled during the summer and fall of 1968. Transmissions from a Convair C-131 aircraft will be used in these tests. The results of the Starr Hill measurements will be reported on in the future.

APPENDIX A

EXPANDED LITTLE IDA PROGRAM

The Expanded Little IDA effort involves the collection and analysis of high frequency propagation data that will assist in the design and operation of over-the-horizon detection systems. Several sophisticated propagation experiments are being conducted over three 2000-nautical mile paths. The paths are (1) a transauroral path between "P" Mountain, Thule, Greenland, and Starr Hill Test Annex, (2) a "parallel-to-the-auroral zone" path from Site Dye 5, Iceland to Starr Hill, and (3) a temperate/semitropical path between Coco Solo Test Annex, Panama Canal Zone and Starr Hill. The Thule, Iceland, and Panama sites transmit their signals to the Starr Hill central receiving site.

The experiments and investigations that are being performed include:

A. 1. Mode Reliability

The object of this experiment is to determine, (1) the availability of the lower order dominant modes (one hop F_2, 2 hop F, etc.), (2) the maximum and lowest observed frequencies used by the individual propagating modes; and (3) the "available frequency aperture" or range of usable frequencies for each mode of propagation. These parameters are being measured as a function of time of day, month, season, and path. This experiment is designed to answer the following questions: "What modes are available and are reliable over the regions of interest at any given time?", "At what frequency or band of frequencies should a radar operate to illuminate a specified region?", and "What upper and lower frequencies, or what range of operating frequencies, should be specified for the design of a specific system?".

A. 2. Mode Loss

The goal of the mode loss experiment is to determine the losses associated with the individual modes that propagate over the three paths. Certain modes, with high availability, may be undesirable due to the high losses associated with them. Because of signal-to-noise considerations, there is a need to ascertain the loss suffered by each mode and the availability of the mode as a function of time of day, month, and season. In addition to the loss measurement, an effort is being made to separate and identify the predominant sources of loss, such as polarization effects, polar cap and auroral zone absorption, focusing, and E_s layer masking.

The analysis of propagation loss due to various mechanisms requires the determination of the total loss between transmitter and receiver and the separation of known losses and gains.

This is further demonstrated by considering the following equation:

$$L_{tot} = L_{bf} + L_p - G_p \tag{A1}$$

where

L_{tot} - is the total system loss between the transmitter and receiver. This quantity is determined from the measurements and is computed directly from the RF power delivered to the transmitting antenna line and the RF power delivered to the receiver.

G_p - is the total antenna power gain for a given mode and is equal to $G_p = 10 \log g_r + 10 \log g_t$ where g_r is the receiving antenna power gain for a particular mode, and g_t is the transmitting antenna power gain for a particular mode. The quantity G_p is determined from the calibrated antenna tests.

L_{bf} - is the basic free space loss or the loss due to the spreading of the electromagnetic wave in space and is defined as:

$$L_{bf} = \frac{4\pi R^2}{\lambda}$$

where R = equivalent distance between transmitter and receiver, and λ = RF wavelength.

L_p - is termed the propagation loss and includes the ionospheric losses and ground reflection losses. The value of L_p and its variability on an individual mode basis as a function of path, time of day, month, and season is the ultimate objective of this experiment.

It is therefore evident that the antennas and transmit/receive systems must be well calibrated so that the system losses and antenna gain parameters may be removed from the measured total loss. In particular, the gain patterns must be well known as a function of elevation and azimuth angles.

This experiment is being conducted over paths that have a 2000 nm range which is the limiting distance for propagation via the one-hop F (1F2) mode. When the 1F2 mode is propagated over these ranges, it is received at extremely low elevation angles (from -1° to +4°). On the other hand, the two hop F_2 mode is received at elevation angles between 12° and 20°. Therefore, the antenna gain patterns must be known as a function of elevation angles that vary from -1° to +20°. In addition, the elevation gain pattern must be known as a function of azimuthal angle since the individual modes may be propagated via off-great-circle paths.

A. 3. Polarization

The objectives of this experiment are (1) to acquire fading statistics (cross-correlation) between signals received on cross-polarized antennas so as to determine whether or not the losses associated with the individual modes are polarization sensitive, and (2) to determine whether or not any of the propagation paths exhibit a preferred polarization as a result of magneto-ionic effects of the ionosphere on wave propagation. To conduct the measurement program for this experiment, the receive site has been instrumented with two arrays, (oriented North and South) consisting of independent log-periodic vertically and horizontally polarized antennas. To adequately perform the measurements, each antenna beam should exhibit a reasonable cross-polarized response of -20 db or less. In addition, it is required that the two independent orthogonally-polarized antenna beams be matched, to within a few db, over the expected vertical arrival angles (0° to 20°).

A. 4. Azimuth of Arrival

The purpose of this investigation is to determine the azimuth of arrival characteristics of the dominant lower modes of propagation. The extent and variability of off-great-circle path propagation of the individual modes is to be determined. At the Starr Hill receive site each antenna array contains two log-periodic vertically polarized dipole antennas (4-64 Mc), arranged at a constant spacing of two-thirds of a wavelength for use as an interferometer. The azimuth of arrival measurement system (antennas and receiver system) must be well calibrated. The results of this calibration (which will also employ aircraft measurement techniques) will be reported on at a later date.

A. 5. Noise and Interference

This effort requires determining as precisely as possible the noise and interference environment within which an OHD system would operate. The investigation involves two separate measurement techniques.

The first technique involves the collection of omni-directional noise data at the Starr Hill site by the standard CCIR (Consultative Committee on International Radio) measurement approach which is used in the world-wide network of noise recording stations. This method utilizes a 22 ft. whip antenna in conjunction with an ARN-2 ESSA (Environmental Science Services Administration) receiving and recording system which measures noise level at 2.5, 5, 10, and 20 MHz. In addition, directional noise data is also measured using a separate ARN-2 receiving system and the log-periodic vertical and horizontal antennas. The measured omni-directional CCIR noise data is compared with (1) predictions published by ESSA and (2) the directional CCIR type noise data to determine if the noise is sensitive to polarization, antenna directivity, and also to obtain a better understanding of the effects of antenna characteristics (high angle reception vs. low angle reception) on noise and interference data.

The second noise measurement technique uses a special purpose dual channel, high dynamic range (120 dB) noise receiver with a frequency range of 4 to 40 MHz. This receiver has the capability of scanning 250, four KHz steps in any of the 36, one MHz bands. This equipment has selectable integration times of 0.3, 3.0 and 500 secs. The 500-second integration time is also common to the ARN-2 receiver. The parameters of this receiver are comparable to those presently under consideration for use in proposed systems. Noise data as a function of frequency, polarization, directivity, and bandwidth are being collected with this equipment at the Starr Hill Site. This type data is more meaningful than the CCIR type for application to OHD problems since the data is gathered on the entire HF band, as well as on directional antennas.

A. 6. Spectrum

The objective of this effort is to determine the effect of the ionosphere and other variables on signal coherence and signal doppler. Signal coherence information pertaining to signals propagating over each of the paths is required so that the system designer may determine the optimum processing format. That is, he may need to utilize coherent integration to achieve a required signal-to-noise ratio. The signal doppler information is required to determine the system's capability in detecting moving targets while operating in a doppler processing mode. These measurements are made on an individual mode basis through use of a spectrum/analyzer magnetic drum processor.

The experiments discussed above are being conducted simultaneously over the three paths of interest. The interdependence of the various parameters is also under investigation in order to better define the overall effect on radar signals propagating over the regions of interest. In the past, these experiments have been performed as separate measurements in themselves. Under this program, defining the relationships existing between the parameters measured is a major task. For example, noise and loss have been treated separately and independently in previous endeavors. On the other hand, there is good reason to believe that these quantities are dependent and are negatively correlated, i.e., when the absorption is high, the noise may be low. The correlation between the loss and noise data is also being determined as a function of the available frequency aperture (range of usable frequencies) so as to be more meaningful for systems application.

From the discussion above, it is evident that the systems employed in the measurement program must be well calibrated. Since the antennas are a major system component, and since the measurements are being made at several frequencies, a detailed antenna gain measurements program is required for the experimental results to be meaningful.

Detailed descriptions of the experiments and instrumentation used are reported on in References 1 through 6.

APPENDIX B

COMPUTER PROGRAM LISTINGS

PROGRAM ANTPATT

```
      PROGRAM ANTPAT
      DIMENSION C(50), CC(50), GR(100), D(100), AT(100), DB(100)
      DIMENSION AA(9), AB(9)
      DIMENSION NF(13)
      DATA((NF(I),I=1,13)=9,11,13,15,16,17,19,21,22,25,26,29,30)
      DIMENSION XX(100),YY(100)
      TYPE REAL LOG10F
C
C     CALIBRATION DATA (DBM)
C
      DATA((CC(I),I=1,11)=115.,110.,105.,100.,95.,90.,85.,80.,75.,
     1 70.,65.)
      DATA((AA(I), I=1,9)= -1., 0., 1., 2., 3., 4., 6., 10., 14.)
      DATA((AB(I), I=1,9)= .7, .45, .31, .22, .16, .13, .09, .05, .03)
      LOG10F(X)=.43429*LOGF(X)
      REWIND 2
C
C     STATEMENTS 407 THROUGH 12 ARE TO BE REMOVED FOR THE FIRST RUN
C        (WHEN NO DATA IS ON TAPE 2)
C     THIS SECTION LOCATES END OF DATA ON TAPE 2
C
  407 READ INPUT TAPE 2,766,NRUM,NPOL,NDATE,NTHD,NRUN,NTIME,NREC,ALTKF,
     1 FREQ,POWE
      IF(NRUM .EQ. 99) 12,75
   75 READ INPUT TAPE 2,777,NPT,(XX(I),YY(I),I=1,NPT)
      GO TO 407
   12 CONTINUE
      BACKSPACE 2
      NFREQ1=0
      NTHD1=0
      CNMKM=1.85325
      CKFNM=0.164462
C
C     SET POLARIZATION----TRANSMIT--RECEIVE--SITE
C        1            =         H     --    H     --STARR HILL
C        2            =         H     --    V     --STARR HILL
C        3            =         V     --    H     --STARR HILL
C        4            =         V     --    V     --STARR HILL
C        5            =         V     --    V     --PANAMA
C        6            =         V     --    H     --PANAMA
C        7            =         V     --    V     --THULE
C        8            =         V     --    H     --THULE
C        9            =         V     --    V     --ICELAND
C        0            =         V     --    H     --ICELAND
C
      NPOL=1                                                           SH-HH
      RENM=3443.2
      RE2=RENM**2
      FPI=4.*3.14159
      CRADDEG=57.2958
C
C     CONSTANT LOSS FACTOR
```

```
C
      CLOSS=60.-20.*LOG10F(300.)+20.*LOG10F(FPI)
C
C     READ FIRST DATA CARD
C
   76 READ 77,NDATE,NTHD,NRUN,NTIME,ALTKF
   77 FORMAT(I6,I3,I2,I4,F10.0)
      IF(NDATE) 10,10,101
   10 NRUM=99
C
C     WRITE DUMMY RECORD ON TAPE 2 , REWIND THE TAPE , END THE PROGRAM
C
  766 FORMAT(I2,I1,I6,I3,I2,I4,I2,3E16.9)
      WRITE OUTPUT TAPE 2,766,NRUM,NPOL,NDATE,NTHD,NRUN,NTIME,NREC,
     1 ALTKF,FREQ,POWE
    8 REWIND 2
      STOP
  777 FORMAT(I2,6E16.9/(6E16.9))
  101 NALT=ALTKF
      IF(NALT) 102,102,103
  102 ALTKF=30.0
C
C     READ SECOND DATA CARD-(NUMBER OF DATA POINTS,RECEIVER NO.,FREQUENCY)
C
  103 READ 11,NPOINT,NREC,FREQ
   11 FORMAT(2I2,F10.0)
      NFREQ=FREQ
      IF(NFREQ.EQ.NFREQ1.AND.NTHD.EQ.NTHD1) 701,702
  701 NRUM=0
      GO TO 108
  702 NRUM=1
      NFREQ1=NFREQ
      NTHD1=NTHD
  108 CONTINUE
C
C     READ THIRD DATA CARD -(POWER IN DBM)
C
      READ 88, POWE
   88 FORMAT(F10.2)
C
C     READ CALIBRATION DATA
C
  104 READ 55,(C(I),I=1,11)
   55 FORMAT(18F4.1)
C
C     PRINT DATA HEADING
C
      PRINT 22,FREQ,NTHD,NRUN,NREC,ALTKF,NDATE,NTIME,POWE,NPOL
   22 FORMAT(1H1,//,5X,10HFREQUENCY=,F10.4,3HMCS,5X,12HTRUE HEADING,I5,
     C5X,7HRUN NO.,I3,/,5X,8HRECEIVER,I3,5X,8HALTITUDE,F5.1,5HKFEET,5X,
     C4HDATE,I8,4X,4HTIME,I8,4X,6HPOWER=,F10.2,2HDB,7X,4HPOL=,I4)
      PRINT 66
```

```
 66 FORMAT(//,5X,5HANGLE,5X,5HRANGE,8X,2HDB,5X,5HATTEN,4X,6HSIGNAL,
   C5X,10HSPACE LOSS,5X,15HSIGNAL STRENGTH,1X,9HLOOP GAIN)
C
C     READ --GROUND RANGES--DIVISIONS--ATTENUATIONS
C
      READ 33,(GR(I), I=1,NPOINT)
      READ 33,(D(I), I=1,NPOINT)
      READ 33,(AT(I), I=1,NPOINT)
 33   FORMAT(15F5.2)
      NPOINT1=0
      I=1
      NNFREQ=FREQ
C
C     SET NFF TO EQUAL THE NUMBER OF THE FREQUENCY-(FROM 1 TO 8)
C
      DO 301 NI=1,13
      IF(NNFREQ .EQ. NF(NI))  302,301
301   CONTINUE
302   NFF=NI
C
C     THIS SECTION (THROUGH STATEMENT 906.) IS REPEATED FOR EACH DATA POINT
C
      DO 906 J=1,NPOINT
C
C     CONVERT DIVISIONS TO DB'S
C
      IF(D(J)-C(1)) 7,2,6
  6   DO 7 I=1,11
      IF(D(J)-C(I)) 3,2,7
  7   CONTINUE
      PRINT 555
555   FORMAT(19H OUT OF CALIBRATION)
      GO TO 906
  2   DB(J)=CC(I)
      GO TO 106
  3   X=D(J)-C(I-1)
      Y = C(I) - C(I-1)
      DB(J)=CC(I-1)+X*(CC(I)-CC(I-1))/Y
C
C     CALCULATE RANGE AND TAKEOFF ANGLE
C
106   GRANNM=GR(J)
      DBREC=DB(J)
      ATTEN=AT(J)
      ALTNM=ALTKF*CKFNM
      AH = RENM + ALTNM
      AH2 = AH**2
      DRAD = GRANNM/RENM
      R2=RE2+AH2-2.*RENM*AH*COSF(DRAD)
      SRANNM = SQRTF(R2)
      SRANKM = SRANNM*CNMKM
      A2 = ALTNM**2
```

```
      SINTOA = (2.*RENM*ALTNM+A2-R2)/(2.*RENM*SRANNM)
      TOAR = ASINF(SINTOA)
      TOA=TOAR*CRADDEG
C
C     CORRECT TAKEOFF ANGLE FOR REFRACTION
C
      IF(TOA .GT. 14) 405, 401
  401 DO 404 IQ = 1,9
      IF(TOA - AA(IQ)) 402, 403, 404
  402 JQ = IQ - 1
      TOA = TOA+AB(IQ)-(AB(IQ)-AB(JQ))*(AA(IQ)-TOA)/(AA(IQ)-AA(JQ))
      GO TO 405
  403 TOA = TOA + AB(IQ)
      GO TO 405
  404 CONTINUE
  405 CONTINUE
C
C     CALCULATE SIGNAL STRENGTH
C
C
C     SUBROUTINE LOOP CALCULATES GAIN OF LOOP RECEIVING ANTENNA
C        (THIS ROUTINE IS NOT USED AT PRESENT)
C
      CALL LOOP(NFF,TOA,ZZ)
      FSL=CLOSS+20.*LOG10F(FREQ)+20.*LOG10F(SRANKM)
      TSIG=DBREC-ATTEN
      SST=FSL-TSIG-POWE+ZZ
C
C     PRINT DATA
C
      PRINT 44,TOA,GRANNM,DBREC,ATTEN,TSIG,FSL,SST,ZZ
   44 FORMAT(5F10.2,5X,F10.2,10X,2F10.2)
C
C     RECORD DATA POINT IN XX AND YY ARRAYS
C
      IF(TOA .GT.25.) 906, 705
  705 NPOINT1=NPOINT1+1
      XX(NPOINT1)=SST
      YY(NPOINT1)=TOA
  906 CONTINUE
C
C     WRITE DATA OUTPUTS ON TAPE 2
C
      WRITE OUTPUT TAPE 2,766,NRUM,NPOL,NDATE,NTHD,NRUN,NTIME,NREC,
     1 ALTKF,FREQ,POWE
      WRITE OUTPUT TAPE 2,777,NPOINT1,(XX(I),YY(I),I=1,NPOINT1)
C
C     READY FOR NEXT DATA RUN
C
      GO TO 76
      END
      SUBROUTINE LOOP(NFF, TOA, ZZ)
      ZZ=0.0
   12 RETURN
      END
```

PROGRAM TAPPLT

```
      PROGRAM TAPPLT
      DIMENSION XX(100), YY(100)
      DIMENSION NF(13),NANG(35),NPL(10)
      DATA((NF(I),I=1,13)=9,11,13,15,16,17,19,21,22,25,26,29,30)
C     STARR HILL
      DATA((NANG(I),I=1,7)=357,2,7,36,183,188,193)
      DATA((NANG(I),I=8,20)=352,12,17,26,31,41,46,178,198,
     1 917,918,919,920)
C     PANAMA
      DATA((NANG(I),I=21,25)=356,1,6,11,16)
C     THULE
      DATA((NANG(I),I=26,30)=179,184,189,194,199)
C     ICELAND
      DATA((NANG(I),I=31,35)=250,255,260,265,270)
C
      DATA((NPL(I),I=1,10)=1,2,3,4,5,6,7,8,9,0)
C
      DIMENSION IFREQ(13),IHEAD(35),IPOL(10)
      DATA((IFREQ(I),I=1,13)=2H9 ,2H11,2H13,2H15,2H16,2H17,2H19,2H21,
     C 2H22,2H25,2H26,2H29,2H30)
C     STARR HILL
      DATA((IHEAD(I),I=1,7)=3H357,3H002,3H007,3H036,3H183,3H188,3H193)
      DATA((IHEAD(I),I=8,20)=3H352,3H012,3H017,3H026,3H031,3H041,3H046,
     1 3H178,3H198,3H917,3H918,3H919,3H920)
C     PANAMA
      DATA((IHEAD(I),I=21,25)=3H356,3H001,3H006,3H011,3H016)
C     THULE
      DATA((IHEAD(I),I=26,30)=3H179,3H184,3H189,3H194,3H199)
C     ICELAND
      DATA((IHEAD(I),I=31,35)=3H250,3H255,3H260,3H265,3H270)
C
      DATA((IPOL(I),I=1,10)=5HSH-HH,5HSH-HV,5HSH-VH,5HSH-VV,5HPAN-V,
     1 5HPAN-X,5HTHU-V,5HTHU-X,5HICE-V,5HICE-X)
C
      YDAT=19.0
      SYMB = 16.
C
C     SET COUNTS/IN., BOARD SCALES, INTERPOLATION DISTANCE
C
      CALL PLTPT(300.,300.,2)
      CALL PLTPT(4.,3.,13)
      CALL PLTPT(5.0,0.0,14)
C
C     START MAIN SEARCH
C
    1 READ 11,KK,K,KKK
   11 FORMAT(3I2)
      IF (K) 1110,1110,111
C     SET PLOTTER IN STANDBY BEFORE ENDING PROGRAM
 1110 CALL PLTPT(0.,0.,5)
      STOP
  111 CONTINUE
```

```
      REWIND 2
      NGO=1
  911 READ INPUT TAPE 2,766,NRUM,NPOL,NDATE,NTHD,NRUN,NTIME,NREC,ALTKF,
     1 FREQ,POWE
  766 FORMAT(I2,I1,I6,I3,I2,I4,I2,3E16.9)
  777 FORMAT(I2,6E16.9/(6E16.9))
      NFREQ=FREQ
      IF(NFREQ.EQ.NF(K).AND.NPOL.EQ.NPL(KK).AND.NTHD.EQ.NANG(KKK)) 77,4
    4 IF(NRUM.EQ. 99) 10,8
   77 READ INPUT TAPE 2,777,NPT,(XX(I),YY(I),I=1,NPT)
      NPOINT1=NPT
      IF(NGO.EQ. 1) 706,7061
C
C     SET PLOTTER IN STANDBY
C
  706 CALL PLTPT(0.,0.,5)
      NGO=0
      IF (XX(1) - XX(NPOINT1))802, 801, 801
  801 RMIN = XX(NPOINT1)
      GO TO 803
  802 RMIN = XX(1)
  803 CONTINUE
C
C     SET PLOTTER OFFSET
C
      NRMIN=RMIN-7.0
      NXOFST=-((NRMIN-1)/4)
      XOFST=NXOFST
      CALL PLTPT(XOFST,1.,3)
      XMOFST=-XOFST
      FRMIN=XMOFST*4.0
C
C     PLOT SCALE
      CALL PLTSC(FRMIN,4.,10.,1,-3.,3.,8.,1)
C
C     SELECT LINE MODE
C
      CALL PLTPT(1.,0.,19)
C
C     SELECT SHORT LINE
C
      CALL PLTPT(1.,0.,4)
      INTEG=4HHEAD
      INTEG2=8HFREQ
      INTEG3=8HDEG
      INTEG4=8HDB
      INTEGX=8H-
      XSTART=FRMIN-5.0
C
C     PLOT HEADING INFORMATION
C
      CALL PLTAL(XSTART,12.,0.25,INTEG3,3)
```

```
      XSTART=FRMIN+20.0
      CALL PLTAL(XSTART,=5.0,0.25,INTEG4,2)
      XSTART=FRMIN+1.0
      CALL PLTAL(XSTART,=7.0,0.25,IPOL(KK),5)
      CALL PLTAL(XSTART,21.,0.25,INTEG,4)
      CALL PLTAL(XSTART,19.,0.25,INTEG2,4)
      XDEC=FRMIN+6.0
      CALL PLTAL(XDEC,21.,0.25,INTEGX,1)
      CALL PLTAL(XDEC,19.,0.25,INTEGX,1)
      XDEC=FRMIN+8.0
      CALL PLTAL(XDEC,21.,0.25,IHEAD(KKK),3)
      CALL PLTAL(XDEC,19.,0.25,IFREQ(K),2)
C
C     SELECT PRINTER MODE
C
      CALL PLTPT(2.,0.,10)
      YDAT=19.
      SYMB=16.
C
C     PRINT RUN INFORMATION
C
      PRINT 22,FREQ,NTHD,NRUN,NREC,ALTKF,NDATE,NTIME,POWE,NPOL
   22 FORMAT(1H1,//,5X,10HFREQUENCY=,F10.4,3HMCS,5X,12HTRUE HEADING,I5,
     C5X,7HRUN NO.,I3,/,5X,8HRECEIVER,I3,5X,8HALTITUDE,F5.1,5HKFEET,5X,
     C4HDATE,I8,4X,4HTIME,I8,4X,6HPOWER=,F10.2,2HDB,7X,3HPOL,I4)
      GO TO 707
 7061 PRINT 33,FREQ,NTHD,NRUN,NREC,ALTKF,NDATE,NTIME,POWE,NPOL
   33 FORMAT(//,15X,F10.4,20X,I5,12X,I3,/,13X,I3,13X,F5.1,14X,I8,8X,
     1 I8,10X,F10.2,12X,I4)
C
C     CHANGE AND SET SYMBOL
C
  707 SYMB=SYMB-1.0
      CALL PLTPT(SYMB,0.,12)
C
C     PRINT DATE INFORMATION
      XSTART=FRMIN+5.0
C
      YDAT=YDAT-2.0
      CALL PLTPT(2.,0.,10)
      CALL PLTPT(XSTART,YDAT+0.375,1)
      DATE=NDATE
      XSTART=FRMIN+9.0
      CALL PLTNU(XSTART,YDAT,DATE,1)
C
C     RESET SYMBOL
C
      CALL PLTPT(SYMB,0.,12)
C
C     SELECT LINE MODE
C
      CALL PLTPT(1.,0.,10)
```

```
C
C     SELECT LONG LINE MODE
      CALL PLTPT(5.,0.,4)
C
C     PLOT PATTERN
C
      CALL PLTPT(XX(1),YY(1),8)
      CALL PLTPT(XX(2),YY(2),16)
      DO 709 IP=3,NPOINT1
      CALL PLTPT(XX(IP),YY(IP),11)
  709 CONTINUE
      CALL PLTPT(2.,0.,19)
C
C     PLOT DATA POINTS
C
      DO 710 IP=1,NPOINT1
      CALL PLTPT(XX(IP),YY(IP),1)
  710 CONTINUE
      GO TO 911
    8 READ INPUT TAPE 2,777,NPT,(XX(I),YY(I),I=1,NPT)
      GO TO 911
   10 GO TO 1
      END
```

PROGRAM DATAVE

```
      PROGRAM DATAVE
      DIMENSION GG(100),SD(100),RR(100),NA(100),R(5,100),G(5,100)
      DIMENSION XX(100),YY(100),NF(13),NANG(35),NPL(10)
      DIMENSION XTW(100),YTW(100)
      DIMENSION N(6),F(3),NPOINT(5)
      COMMON R,G,NRUNS,NPOINT,GG,SD,RR,NA,K,KK,KKK
      DATA((NF(I),I=1,13)=9,11,13,15,16,17,19,21,22,25,26,29,30)
C     STARR HILL
      DATA((NANG(I),I=1,7)=357,2,7,36,183,188,193)
      DATA((NANG(I),I=8,20)=352,12,17,26,31,41,46,178,198,
     1 917,918,919,920)
C     PANAMA
      DATA((NANG(I),I=21,25)=356,1,6,11,16)
C     THULE
      DATA((NANG(I),I=26,30)=179,184,189,194,199)
C     ICELAND
      DATA((NANG(I),I=31,35)=250,255,260,265,270)
C
      DATA((NPL(I),I=1,10)=1,2,3,4,5,6,7,8,9,0)
C
C     READ SEARCH PARAMETERS
C
    1 READ 11,KK,K,KKK
   11 FORMAT(3I2)
      IF(K) 10,10,2
   10 STOP
    2 NRUNS=0
      DO 3 I=1,5
    3 NPOINT(I)=0
C
C     SEARCH IS STARTED
C
  913 READ INPUT TAPE 2,766,(N(I),I=1,7),(F(I),I=1,3)
  766 FORMAT(I2,I1,I6,I3,I2,I4,I2,3E16.9)
      NFQ=F(2)
      IF(NFQ.EQ.NF(K).AND.N(4).EQ.NANG(KKK).AND.N(2).EQ.NPL(KK))8,4
    4 IF(N(1).EQ.99) 6,5
C
C     SEARCH IS ENDED--READY FOR AVERAGING
C
    6 CALL AVERAGE
      REWIND 2
C
C     READY FOR NEXT PARAMETER
C
      GO TO 1
    5 READ INPUT TAPE 2,777,NTW,(XTW(I),YTW(I),I=1,NTW)
  777 FORMAT(I2,6E16.9/(6E16.9))
      GO TO 913
    8 READ INPUT TAPE 2,777,NPT,(XX(I),YY(I),I=1,NPT)
C
C     RECORD DATA IN G AND R ARRAYS
```

```
C
      NRUNS=NRUNS+1
      NPOINT(NRUNS)=NPT
      DO 7 I=1,NPT
      G(NRUNS,I)=XX(I)
      R(NRUNS,I)=YY(I)
    7 CONTINUE
C
C     CONTINUE SEARCH
C
      GO TO 913
      END
      SUBROUTINE AVERAGE
      COMMON R, G, NCURVE, NPOINT1, GG, SD, RR, NA,K9, KK, KKK
      DIMENSION SD(100), RR(100), GA(4)
      DIMENSION R(5,100), G(5,100),NPOINT1(5), NA(100), GG(100)
      DIMENSION  NF(13),NANG(35),IPOL(10)
      DATA((NF(I),I=1,13)=9,11,13,15,16,17,19,21,22,25,2[illegible],29,30)
C     STARR HILL
      DATA((NANG(I),I=1,7)=357,2,7,36,183,188,193)
      DATA((NANG(I),I=8,20)=352,12,17,26,32,41,46,178,198,
     1 917,918,919,920)
C     PANAMA
      DATA((NANG(I),I=21,25)=356,1,6,11,16)
C     THULE
      DATA((NANG(I),I=26,30)=179,184,189,194,199)
C     ICELAND
      DATA((NANG(I),I=31,35)=250,255,260,265,270)
      DATA((IPOL(I),I=1,10)=5HSH-HH,5HSH-HV,5HSH-VH,5HSH-VV,5HPAN-V,
     1 5HPAN-X,5HTHU-V,5HTHU-X,5HICE-V,5HICE-X)
      TYPE REAL LOG10F
      LOG10F(X) = .43429 * LOGF(X)
C
C     PUT CURVES IN ORDER--(LOWEST ANGLES TO HIGHEST ANGLES)
C
      DO 30 N = 1, NCURVE
      NP = NPOINT1(N)
      IF(R(N,1) - R(N,NP)) 30, 31, 31
   31 NP2 = NP/2
      DO 12 I = 1, NP2
      NPP = NP - I + 1
      TEMP = R(N,I)
      R(N,I) = R(N,NPP)
      R(N,NPP) = TEMP
      TEMP = G(N,I)
      G(N,I) = G(N, NPP)
      G(N,NPP) = TEMP
   12 CONTINUE
   30 CONTINUE
C
C     FOR ONE CURVE
C
      IF(NCURVE.LE.1) 101,103
  101 NNN=NPOINT1(1)
```

```
      NPOINT=NNN
      DO 102 I=1,NNN
      SD(I)=0.
      GG(I)=G(1,I)
      NA(I)=1
      RR(I)=R(1,I)
  102 CONTINUE
      GO TO 18
  103 CONTINUE
C
C     FIND THE LONGEST CURVE
C
      NPOINT = 0
      DO 50 II = 1, NCURVE
      IF(NPOINT1(II)-NPOINT) 50, 50, 51
   51 NPOINT = NPOINT1(II)
      NC=II
   50 CONTINUE
C
C     THIS SECTION (THROUGH STATEMENT 6 IS REPEATED FOR EACH   POINT
C
      DO 6 J = 1, NPOINT
C
C     SET UP RANGE ARRAY
C
      RR(J) = R(NC,J)
      RRA = RR(J)
C
C     CALCULATE GAINS AT THE ANGLES
C
      DO 14 I = 1, NCURVE
      NP = NPOINT1(I)
      IF(R(I,NP)-RRA) 20, 22, 22
   22 IF(R(I,1) - RRA) 21, 21, 20
   20 GA(I) = 100.
      GO TO 14
   21 DO 1 K = 1, NP
      IF(R(I,K)-RRA) 1, 2, 3
    2 GA(I) = G(I,K)
      GO TO 14
    3 K1 = K-1
      GA(I) = G(I,K) - (G(I,K)-G(I,K1))*(R(I,K)-RRA)/(R(I,K)-R(I,K1))
      GO TO 14
    1 CONTINUE
   14 CONTINUE
C
C     CALCULATE AVERAGE GAIN
C
      GG(J) = 0,    $    S = 0.    $   NA(J) = 0
      DO 5 L=1,NCURVE
      IF(GA(L)-50.) 7, 7, 5
    7 NA(J) = NA(J) + 1
```

```
      POWER = GA(L)/10.
      GA(L) = 10.**POWER
      GG(J) = GG(J) + GA(L)
    5 CONTINUE
      GG(J) = GG(J)/NA(J)
      GGREG=GG(J)
      GG(J) = 10. * LOG10F(GG(J))
C
C     CALCULATE STANDARD DEVIATION
C
      DO 8 L = 1, NCURVE
      IF(GA(L) - 50.) 40, 40, 8
   40 S = S + (GA(L)- GGREG)**2
    8 CONTINUE
      S = S/NA(J)
      S = SQRTF(S)
      SD(J)=(4.3429*S)/GGREG
C
C     READY FOR NEXT POINT
C
    6 CONTINUE
C
C     PRINT INFORMATION
C
   18 CONTINUE
      PRINT 98,NF(K9),IPOL(KK),NANG(KKK)
   98 FORMAT(//,5X,10HFREQUENCY=,I4,5X,18HSITE-POLARIZATIONS=,2X,A5,5X,
     1 6HANGLE=,I4)
      PRINT 999
  999 FORMAT(12X,8HAVE GAIN,15X,5HANGLE,12X,8HSTD.DEV.,6X,6HPOINTS)
      PRINT 99,(GG(I),RR(I),SD(I),NA(I),I=1,NPOINT)
   99 FORMAT(3F20.4, 10X, I2)
C
C     READY TO PLOT INFORMATION
C
  908 CALL PLOT(GG,RR,K9,KK,KKK,NPOINT)
  108 RETURN
      END
      SUBROUTINE PLOT(XX,YY,K,KK,KKK,NPOINT1)
      DIMENSION XX(100),YY(100)
      DIMENSION IFREQ(13),IHEAD(35),IPOL(10)
      DATA((IFREQ(I),I=1,13)=2H9 ,2H11,2H13,2H15,2H16,2H17,2H19,2H21,
     C 2H22,2H25,2H26,2H29,2H30)
C     STARR HILL
      DATA((IHEAD(I),I=1,7)=3H357,3H002,3H007,3H036,3H183,3H188,3H193)
      DATA((IHEAD(I),I=8,20)=3H352,3H012,3H017,3H026,3H031,3H041,3H046,
     1 3H178,3H198,3H917,3H918,3H919,3H920)
C     PANAMA
      DATA((IHEAD(I),I=21,25)=3H356,3H001,3H006,3H011,3H016)
C     THULE
      DATA((IHEAD(I),I=26,30)=3H179,3H184,3H189,3H194,3H199)
C     ICELAND
```

```
      DATA((IHEAD(I),I=31,35)=3H250,3H255,3H260,3H265,3H270)
C
      DATA((IPOL(I),I=1,10)=5HSH-HH,5HSH-HV,5HSH-VH,5HSH-VV,5HPAN-V,
     C 5HPAN-X,5HTHU-V,5HTHU-X,5HICE-V,5HICE-X)
      DATA (NSTART=0)
      IF (NSTART .EQ. 0) 404,602
  404 CONTINUE
      NSTART=1
      NFREQP=0
      CALL PLTPT(300.,300.,2)
      CALL PLTPT(4.,3.,13)
      CALL PLTPT(5.0,0,0,14)
  602 IF(NFREQP .EQ. K) 604,421
  421 CONTINUE
      CALL PLTPT(0.,0.,5)
      NFREQP=K
      RMIN=XX(1)
      NRMIN=RMIN-5.0
      NXOFST=-((NRMIN-1)/4)
      XOFST = NXOFST
      CALL PLTPT(XOFST,1.,3)
      XMOFST = -XOFST
      FRMIN=XMOFST*4.0
      CALL PLTSC(FRMIN,4.,10.,1,-3.,3.,8.,1)
      CALL PLTPT(1.,0.,19)
      CALL PLTPT(1.,0.,4)
      INTEG=4HHEAD
      INTEG2=8HFREQ
      INTEG3 = 8HDEG
      INTEG4 = 8HDB
      INTEGX=8H-
      XSTART=FRMIN-5.0
      CALL PLTAL(XSTART,12.,0.25,INTEG3,3)
      XSTART = FRMIN + 20.0
      CALL PLTAL(XSTART,-5.0,0.25,INTEG4,2)
      XSTART=FRMIN+1.0
      CALL PLTAL(XSTART,-7.0,0.25,IPOL(KK),5)
      CALL PLTAL(XSTART,21.0,0.25,INTEG2,4)
      CALL PLTAL(XSTART,19.0,0.25,INTEG,4)
      XDEC=FRMIN+6.0
      CALL PLTAL(XDEC,21.,0.25,INTEGX,1)
      XDEC=FRMIN+8.0
      CALL PLTAL(XDEC,21.,0.25,IFREQ(K),2)
      HPOS=21.0
      SYMB=16.
  604 HPOS=HPOS-2.0
  707 SYMB = SYMB-1.
      CALL PLTPT(2.,0.,19)
      CALL PLTPT(SYMB,0.,12)
      XDEC=FRMIN+5.0
      CALL PLTPT(XDEC,HPOS+0.375,1)
      CALL PLTPT(1.,0.,19)
```

```
      CALL PLTPT(1.,0.,4)
      XDEC=FRMIN+6.0
      CALL PLTAL(XDEC,HPOS,0.25,INTEGX,1)
      XDEC=FRMIN+8.0
      CALL PLTAL(XDEC,HPOS,0.25,IHEAD(KKK),3)
      CALL PLTPT(5.,0.,4)
      CALL PLTPT(XX(1),YY(1),8)
      CALL PLTPT(XX(2),YY(2),16)
      DO 709 IP=3,NPOINT1
      CALL PLTPT(XX(IP),YY(IP),11)
  709 CONTINUE
      CALL PLTPT(2.,0.,19)
      CALL PLTPT(SYMB,0.,12)
      DO 710 IP=1,NPOINT1
      CALL PLTPT(XX(IP),YY(IP),1)
  710 CONTINUE
      RETURN
      END
```

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13. ABSTRACT

This report describes the data collection, reduction, and processing techniques employed in an antenna gain measurements program. This gain measurements program is an integral part of the overall Expanded Little Ida effort, ~~Air Force Project 5582~~.

The gain patterns of transmitting antennas located at Thule, Greenland; Keflavik, Iceland; and Coco Solo, Panama Canal Zone were determined and the results reported herein. Descriptions of the instrumentation (site and aircraft) used to obtain the data, and descriptions of the manual and computer processing methods employed are discussed.

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